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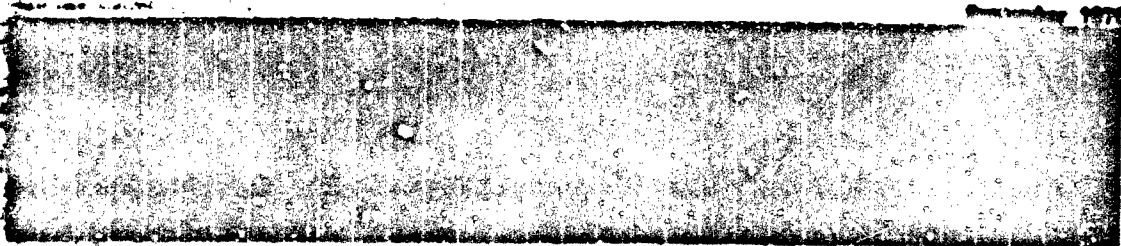
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COMPARISON OF SPECIFICATIONS FOR HEAD-UP
DISPLAYS IN THE NAVY A-4E, A-7E,
AV-8A, AND F-14A AIRCRAFT

Lawrence H. Post

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10 Lawrence H. Frank

9 Special report

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FORN
JAN 30 1982
RESERVE

Naval Air Systems Command
F55-525-401-8881

Naval Medical Research and Development Command
F51524, SP5552542

17

16 F51524, F55525

Approved by:

Released by:

Ashton Graybiel, M.D.
Assistant for Scientific Programs

Captain R. E. Mitchel, MC, USN
Commanding Officer

14 NAMIKH-79-6

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11 5 November 1979

Naval Aerospace Medical Research Laboratory
Naval Air Station
Pensacola, Florida 32508

406 061

SUMMARY PAGE

THE PROBLEM

The purpose of this report is to provide within a single document, a compendium of data on Head-up Displays (HUDs) in U. S. Navy and U. S. Marine Corps aircraft that is germane to a Human Factors assessment of HUD design on pilot performance.

The data in this report were compiled from current Naval Air Training and Operating Procedures Standardization (NATOPS) manuals and design specifications for each of the HUD units.

FINDINGS

Operational HUDs were found to vary dramatically from each other and the military specification for HUDs, MIL-D-81841 (AS), with respect to symbology and formatting. Furthermore, display clutter was reported by pilots to be a major problem. A comprehensive information processing evaluation of virtual image symbols and formatting under dynamic conditions was recommended.

Finally, none of the current Navy aircraft has a HUD control panel that complies to MIL-D-81841 (AS), the military specification for HUDs. Pilots are required to bring their eyes back "into" the cockpit to ensure proper switch selection and, consequently, negate the primary purpose of maintaining a head-up mode.

ACKNOWLEDGMENT

The author wishes to express his appreciation to Captain J. E. Goodson, MSC, USN (Ph.D) for his time, ideas, and comments.

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I. INTRODUCTION

Head-up displays (HUDs) utilize cathode ray tubes and collimating optics to project display information on a combining glass mounted in front of the pilot's eyes. By looking through the combiner, the pilot can monitor instrument display symbology and real-world targets at similar optical distances, and then reduce the need for reaccommodation when looking from one to the other. Advances in HUD technology have progressed at a rapid pace and have produced a variety of HUD models. The U. S. Navy and U. S. Marine Corps have four operational aircraft that carry HUDs. These aircraft are the A-4M, A-7E, AV-8A, and F-14A. With the addition of the forthcoming F-18, there will be five HUDs which have been designed to accommodate specific Navy and Marine Corps aviation missions and weapons delivery systems. Table I presents the nomenclature and manufacturer for each of these five HUD systems.

Unfortunately, the Human Factors evaluation of HUDs has not kept pace with technological advances. The Human Factors Engineering specification dealing with HUDs, MIL-D-81641 (AS), is based primarily on expert opinion and not on data from controlled experiments. Consequently, research on how HUD design affects pilot performance needs to be done. Egan and Goodson (3) have reviewed MIL-D-81641 (AS) and the Human Factors literature on HUDs and have made recommendations for research. However, specific information on the design of operational HUDs is difficult to collect and collate due to the limited distribution of design specifications, and the recurrent updating of the Naval Air Training and Operating Procedures Standardization (NATOPS) manuals.

The present report provides a compendium of data on operational HUDs in U. S. Navy and U. S. Marine Corps aircraft that is germane to a Human Factors assessment of the effects of HUD design on pilot performance. The data in this report were primarily compiled from current NATOPS manuals and detailed design specifications for each of the HUD units. Interviews with pilots provided anecdotal information. The report is presented in two sections. First, specific comparisons are made among the formats and symbologies found in operational HUDs and those recommended in MIL-D-81641 (AS). Then, the HUD control units are reviewed with respect to control switch type, location, nomenclature, function, and mode of operation.

II. HUD SYMBOLOGY

COMPARISONS OF SYMBOLS ACROSS AIRCRAFT

Table II presents the HUD symbols used in the A-4M, A-7E, AV-8A, and F-14A aircraft and the symbols specified in MIL-D-81641 (AS) (1-10, 12-15). It should be noted that Table II depicts only the form of each symbol and is not a representative comparison of symbol size and line width. When an aircraft did not have a symbol that was functionally the same as that specified by MIL-D-81641 (AS), a NONE was entered for that cell of Table II.

Table 1

HUD Nomenclature and Manufacturer by Aircraft

Aircraft	Nomenclature	Manufacturer
A-4M	AN/AVQ-24	Marconi-Elliott (E-A Industrial Corporation)
A-7E	AN/AVQ-7	Marconi-Elliott (E-A Industrial Corporation)
AV-8A	None	Smith Industries
F-14A	AN/AVQ-12	Kaiser Aerospace & Electronics Corporation
F-18	None	Kaiser Aerospace & Electronics Corporation

Table II
Comparison of HUD Symbology

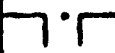










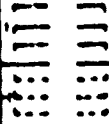
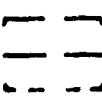
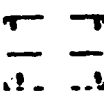
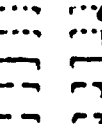
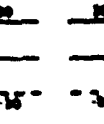
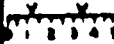


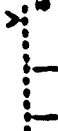
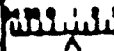









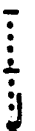
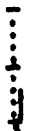

SYMBOL \ AIRCRAFT	NO. D-81641 (AS)	A-4M	A-7E	AV-8A	F-14A
VELOCITY VECTOR		NONE		NONE	
FLIGHT DIRECTOR		NONE		NONE	
ANGLE OF ATTACK ERROR		INDICATED BY POSITION OF AIRCRAFT REFERENCE 			
PITCH & HORIZON					
RANGE				NONE	
HEADING					
VERTICAL VELOCITY		NONE			
AIRSPEED				330	

Table II
Comparison of HUD Symbology (Cont'd)


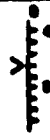



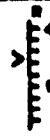









































<div> <div>SYMBOL</div> <div>AIRCRAFT</div> </div>	ML-D-8641 (AS)	A-4M	A-7E	AV-8A	F-14A
MACH NUMBER		NONE	NONE	0.84	.26
BAROMETRIC ALTITUDE				22,800	
RADAR ALTITUDE				82,521	
RUNWAY		NONE	NONE	NONE	NONE
AIRCRAFT RETICLE	> <	NONE	NONE	NONE	
TERRAIN CARPET		NONE	NONE	NONE	NONE
OPTIMUM WEAPON RELEASE CUE				NONE	
PULLUP INTERDICTION CUE				NONE	

Table II
Comparison of HUD Symbolology (Cont'd)

SYMBOL	MIL-D-81641 (AS)	A-4M	A-7E	AV-8A	F-14A
BREAKAWAY					
WARNING INDICATOR				NONE	
BOMB FALL LINE		NONE		NONE	
CLOSURE RATE		NONE	NONE	NONE	
TARGET, BOMBS, GUNS, ROCKETS & CLOSE-UP MISSILES					
AIMING RETICLE					
STANDBY RETICLE				NONE	NONE

As can be readily observed from Table I., symbology varies dramatically across aircraft. As has been previously noted by Egan and Goodman (3), little is known of what display symbology is best from a human factors engineering standpoint.

DISPLAY MODES AND DISPLAY CLUTTER

Figures 1 through 6 present the display modes according to MIL-D-81841 (AS) for takeoff/navigation, terrain-following, bombing, boresight weapon, guided weapon, and landing. Figure 7 depicts the specified field of view and appropriate symbol locations. Display and test modes are shown for the A-4M in Figures 8 through 10, the A-7E in Figures 11 and 12, the AV-8A in Figures 13 and 14, and the F-14A aircraft in Figures 15 through 28.

As can be observed from Figures 1 through 28, the display formats vary considerably across the aircraft and do not conform to MIL-D-81841 (AS). Some obvious differences between the display formats are the shape, the number, and the arrangement of the symbols presented during any particular mode. It is difficult to argue that MIL-D-81841 (AS) defines the optimal set of symbols and formats to be used, since experimental data on virtual image symbols and formats are minimal. However, it would seem appropriate for the formats to conform to Navy specifications in order to maintain standardization across aircraft.

Anecdotal evidence from pilots indicates that display clutter is a major problem. This is supported by a survey (11) which indicated that A-7 pilots turned their HUD off because they felt it interfered with their performance. Display clutter is the most common subject of complaint by pilots. Pilots would like to have a greater control over the information presented on the HUD during the various phases of their missions. The declutter switch on the A-4M and on the F-14A was designed with this purpose in mind. However, A-4M and F-14A pilots still argue that they do not have enough control over the displays.

An initial step in minimizing display clutter would be to determine what information is essential for each mode, and present only that information on the HUD. For example, attack pilots report that during a dive bombing run, altitude, heading, airspeed, and pullup anticipation cue symbols are not monitored and need not be displayed. These symbols are reported to distract the pilot and interfere with his ability to maintain the HUD target symbol in alignment with the designated bomb target.

It should be remembered that the displays depicted in Figures 1 through 28 are dynamic displays. Symbols are constantly moving or changing their values. Research on dynamic virtual image displays is essentially non-existent. A simple yet dramatic example of the impact of symbology movement in HUDs can be shown in the AV-8A. As shown in Table II, the AV-8A has digital altitude and airspeed symbols. When the aircraft is in relatively stable flight, such as in a hover or flying the airways, the altitude and airspeed displays can be easily read. How-

ever, when the plane is in a dive or a climb, the pilot cannot accurately read either display because of the plane's rapidly changing altitude and airspeed. The need for a comprehensive information processing evaluation of virtual image symbols and formatting under dynamic conditions should be obvious.

III. PILOT CONTROL UNITS

Detailed descriptions of switch type, location, nomenclature, function, and operational modes for each of the pilot HUD control units are presented in this section, along with the modes of operation and manual controls specified by MIL-D-81841 (AS).

A. A-4M (AN/AVQ-24)

The A-4M is a single seat attack aircraft.

Control Location and Switch Type

Figure 28 presents the HUD control unit in the A-4M as viewed from the pilot's seat. The HUD in the A-4M is referred to as the Digital Display Indicator and is located on the top center portion of the instrument panel. The controls for the HUD are located on the port, starboard, and aft sections of the unit. On the port side of the HUD there is a three position toggle switch labeled test, N, and DCLUTR. A rotary switch on the port side serves as the on/off and brightness control. On the starboard side of the HUD unit, a three position rotary switch is located that functions as the on/off and brightness control for the standby reticle. The aft portion of the HUD has a rotary QFE switch, a rotary wingspan switch, a three position toggle switch labeled 1, 2, and 3, and a rotary mode selector switch labeled A/A, NAV, CCIP, BARO, and MSL.

Table III presents the HUD control nomenclature and function descriptions for the A-4M aircraft (8).

Modes of Operation

The A-4M HUD has six modes of operation. The display format for each mode is presented in another portion of this report.

1. Air-to-Air (Fig. 9)
2. Air-to-Ground (BARO) (Figs. 8, 10)
3. Air-to-Ground (CCIP) (Figs. 8, 9)
4. Navigate (Fig. 8)

Table III

**HUD Control Nomenclature and Function for the
A-4W Aircraft***

Control Nomenclature	Function
STBY RTCL OFF/BRT	Combined switch potentiometer selects ON/OFF and controls brilliance of standby sight symbol.
HUD OFF/BRT	Combined switch potentiometer selects ON/OFF, and adjusts CRT symbol brilliance.
WINGSPAN (W/SPAN)	Provides adjustment for target wingspan between 20 and 120 feet. Adjusts missile bore-sight circle diameter when in missile mode.
QFE	Provides adjustment to local barometric pressure altitude.
NTN 1 2 3	Three-position switch used to select type of weapon.
TEST/N/DCLUTR	Three-position toggle switch. 1. Upper position - provides a fixed, self-test display 2. Center position - provides a normal system operation according to mode selector 3. Lower position (DCLUTR) - removes speed, altitude, and heading indicator symbols from display
Mode select switch (BARO position)	Digital display indicator displays barometric release air-to-ground (BARO) symbology.
Mode select switch (CCIP position)	Digital display indicator displays continuously computed impact point air-to-ground (CCIP) symbology.

Table II
(Continued)

**HUD Control Nomenclature and Function for the
A-4M Aircraft***

Control Nomenclature	Function
Mode select switch (NAV position)	Digital display indicator displays navigation symbology including: heading scale, pitch and roll attitude, air speed, and altitude scale.
Mode select switch (A/A position)	Digital display indicator displays aiming sight, range octagon, tracer line, and guncross air-to-air symbology.
Mode select switch (MSL position)	Digital display indicator displays missile symbology guncross symbol used for missile boreighting. Missile boreight circle varied by wingspan control and pilot set to boreight tolerance allowable one missile selected.

*Adapted from A-4M NATOPS

5. Missile (Fig. 10)

6. Standby (Fig. 9)

Other HUD Inputs

Inputs to the A-4M HUD, other than those on the unit itself, can be made through computer control. Manual inputs through the computer control panel located on the upper port section of the instrument panel include: depression, windspeed, wind heading, drift, release altitude, and target altitude information required for weapon delivery. A thumbwheel located on the forward face of the turret serves as a range control used in air-to-air calculation of stadiametric range.

B. A-7E (AN/AVQ-7)

The A-7E is a single-seat attack aircraft.

Control Location and Switch Type

Figure 30 presents the HUD control unit in the A-7E as viewed from the pilot's seat. The HUD in the A-7E is referred to as the Pilot's Display Unit, and is located on the top center portion of the control panel. The in-range indicator (IN RNG) is located on the aft-starboard combiner support. A combiner position level is located on the aft-port combiner support. The remainder of the controls are positioned on the after section of the Pilot's Display Unit and include the following: a two position toggle switch for panel light control, a rotary switch for HUD on/off and brightness control, a rotary switch for standby reticle on/off and brightness control, a two position toggle switch for selecting barometric or radar altitude, a two position toggle switch for test display presentation, a rotary filter knob for inserting or removing the night filter, and a rotary standby reticle depression switch. Also located on the after portion of the control unit is a K/L indicator window which displays the depression angle of the standby reticle.

Table IV presents the HUD control nomenclature and function for the A-7E aircraft (9).

Modes of Operation

The A-7E has ten modes of operation. The display formats for each mode are presented in Figures 11 and 12.

1. Radar Bomb (Fig. 11)

2. Radar Bomb Offset (Fig. 11)

Table IV

**HUD Control Nomenclature and Function for the
A-7E Aircraft***

Control Nomenclature	Function
IN RNG indicator:	ON - indicates FLR is in AGR mode and is locked on a target within a preselected range. Range is set on the Range Set thumbwheel control on instrument panel. The light is not controlled by the Tactical Computer.
PNL LTS switch	PNL LTS - turns on HUD panel lights. OFF - turns off HUD panel lights.
STBY RETICLE power and brightness control.	BRT - clockwise rotation applies power to standby reticle and increases reticle brightness. OFF - full counterclockwise rotation turns off standby reticle.
TEST switch	TEST - initiates built-in self-test. OFF - disconnects self-test.
MILE indicator	Indicates depression angle of standby reticle in miles.
Standby reticle depression knob.	DEPR - clockwise rotation adjusts the standby reticle depression angle from zero to 210 mils. Two detent positions are provided, one at the zero position and one at approximately 87 mils (5°).
BARO ALT/RDR ALT switch	BARO ALT - causes barometric altitude to be indicated on HUD altitude scale. RDR ALT - causes Radar Altimeter altitude to be indicated on the HUD altitude scale with an index mark beneath the numeric. When the Radar Altimeter is not locked on, the HUD altitude scale will indicate 0.

**Table IV
(Continued)**

**HUD Control Nomenclature and Function for the
A-7E Aircraft***

Control Nomenclature	Function
FILTER knob	DAY - removes night filter from field of view. NIGHT - inserts filter in front of lens.
SCALES switch	SCALES - displays airspeed, altitude, vertical velocity, and heading symbology. OFF - removes scales from display.
HUD power and brightness control	ERT - clockwise rotation applies power to the HUD and increases symbol brightness. OFF - full counterclockwise rotation turns off the HUD except for the standby reticle.
Combiner position lever	Permits fore and aft movement of combiner glass to raise and lower HUD field of view.

*Adapted from A-7E NATOPS.

3. Normal Attack (Fig. 11)
4. Normal Attack Offset (Fig. 11)
5. Terrain Following (Fig. 11)
6. Landing (Figs. 11, 12)
7. Navigation Bomb (Fig. 11)
8. Data Link (Fig. 11)
9. Gun Hi/Gun Low (Fig. 11)
10. Standby (Fig. 11)

Other HUD Inputs

Mode selection in the A-7E is accomplished through external signals supplied to the HUD from the Master Function Selectors. The Master Function selectors are a series of pushbuttons located on the port instrument panel. Table V presents a listing of the Master Function Selectors and their functions (9).

A slew control for the HUD aiming symbol is positioned on the aircraft's port instrument console. This "joystick" permits movements of the HUD aiming symbol in elevation and azimuth. A reticle slew thumbwheel, which is currently disabled, is located on the base of the throttle grip and is designed to slew elevation commands to the HUD aiming symbol.

C. AV-8A

The AV-8A is a single seat attack, vertical short takeoff and landing (V/STOL) aircraft. The TAV-8A is a tandem two-seat V/STOL trainer. The front cockpit of the TAV-8A is basically identical to the single-seat AV-8A's cockpit. The HUDs in each aircraft are identical. However, the TAV-8A also has a HUD in the aft cockpit. Therefore, in the following descriptions, controls and functions will be identified with respect to cockpit. References to the front cockpit are applicable to both aircraft.

Control Location and Switch Type

Figures 31 and 32 present the HUD and the HUD control panel, respectively, for the AV-8A aircraft. The pilot's HUD control panel is located in the forward cockpit, above the port instrument console. Controls on the control panel include the following: a six-position rotary mode selector knob, a rotary display brightness control, a two-position toggle switch for

Table V

Master Function Selectors for the A-7E Aircraft*

Control Nomenclature	Function
RADAR BOMB	Selects the Radar Bomb mode of attack for the weapons delivery system.
NORM ATTACK	Selects the Normal Attack mode for the weapons delivery system. Used for computed lead for rockets and air-to-ground gun mode.
TF	Selects Terrain Following mode. Causes HUD and ADI to display TF and Navigation mode symbology.
LDG	Selects the Automatic Carrier Landing System (ACLS). Causes the HUD to display landing symbology. The HSI displays TACAN distance and bearing.
OFFSET	Used in conjunction with the Normal Attack or Radar Bomb mode to attack a target that may not be visible but can be located in relation to an offset aimpoint (OAP).
NAV BOMB	Selects the Navigation Bomb mode. Uses target coordinates, as stored in the Tactical Computer, as a normal destination.
DATA LINK	Decouples the Tactical Computer and couples Data Link guidance.
GUN HI/GUN LOW selectors	Selects the computer air-to-air gun attack mode. HUD displays lead computing aiming symbol. Computer updates are not possible in this mode.

*Adapted from A-7E NATOPS.

displaying the speed error symbol, a rotary switch for adjusting set speed, a two-position toggle switch for selecting indicated airspeed or mach number, a two-position toggle on/off switch for selecting UHF homer, a two-position toggle on/off switch for selecting angle of attack, a two-position toggle switch for selecting radio or barometric altitude, a two-position toggle switch for selecting or deselecting TACAN steering, two push-buttons labeled "Test" and "2" that allow test patterns to be displayed, a rotary switch for setting barometric pressure datum, and a rotary switch for selecting air-to-air gun mode and target wingspan adjustment.

Table VI presents the HUD control nomenclature and function for the AV-8A and TAV-8A aircraft (7).

Modes of Operation

The AV-8A has four modes of operation. The display formats for each mode are presented in Figures 13 and 14.

1. V/STOL (Fig. 13)
2. NAVIGATION (Fig. 13)
3. WEAPONS A (Fig. 13)
4. WEAPONS B (Fig. 13)

Although a fifth mode, Weapons C, is provided for on the HUD control panel, it is currently inoperative.

Other HUD Inputs

A HUD override panel is located on the port section of the aft cockpit's instrument panel. The panel has a three-position rotary switch labeled NORM, V/STOL, and NAV. When V/STOL or NAV are selected, selections in the front cockpit are overridden. When NORM is selected, the HUD control panel mode selections are displayed.

A HUD display panel is located on the starboard instrument console in the aft cockpit.

The panel contains two preset adjustments labeled PANEL PRESET, two test buttons labeled TEST 1 and TEST 2, two preset adjustments labeled H, two preset adjustments labeled XC and YC, and a control knob labeled DIM. The PANEL PRESET adjustments are made before flight to set the brightness level of the rear HUD unit. The test buttons, when depressed, cause a test pattern to be displayed on both HUD units. If TEST 1

Table VI

**HUD Control Nomenclature and Function for the
AV-8A Aircraft***

Control Nomenclature	Function
HUD mode selection knob.	The mode selector knob, labeled OFF, V/STOL, NAV, WPNS A, WPNS B, WPNS C, switches the HUD system on and selects the symbols required for normal flight modes. The WPNS C mode is inoperative. Rotating the knob out of the OFF position energizes the HUD system and enables the UHF homing steering bar. Selecting the NAV position selects the navigation display. Selecting the V/STOL position selects a V/STOL display which is similar to the navigation display except for the added sideslip indication. Optional symbol presentations in the two modes also vary. The WPNS A and WPNS B modes are air-to-ground weapon aiming modes. Air-to-air weapon aiming displays are selected with the wingpan setting knob.
Display Brightness Control.	A knob labeled DIM adjusts the display intensity to a contract level which is maintained automatically by the solar cell unit.
Error Scale Switch.	The ON position is labeled ERROR SCALE. The speed error symbol is displayed when the switch is ON.
Set Speed Control.	A knob, labeled SET SPEED, causes digits indicating demanded speed to be displayed when the knob is pushed against its spring-loading. The demanded speed displayed can be adjusted by rotating the set speed control knob.
IAS/MACH Selector Switch.	Determines whether IAS or Mach number is displayed in the NAV mode.

**Table VI
(Continued)**

**HUD Control Nomenclature and Function for the
AV-8A Aircraft***

Control Nomenclature	Function
UHF Homer Selector Switch.	Labeled HOMER when in the UP position, permits a UHF homer symbol to be displayed on the HUD.
AOA Selector Switch.	Labeled ADD, when in the UP position, permits an angle of attack symbol to be displayed on the HUD.
Radio/Baro Switch.	Radar altimeter height can be displayed by positioning the radio/baro switch to RADIO. The number displayed is preceded by the letter R. Radar height display is available in all modes except air-to-air. Placing the switch to BARO causes barometric height to be displayed on the HUD.
TACAN Switch.	Placing this switch to the UP position permits a TACAN steering symbol to be displayed on the HUD.
BIT Test Buttons 1 and 2.	Permits built-in test equipment (BIT) tests to be made. When one of the buttons is depressed an associated test is initiated and a test pattern is displayed for as long as the button is held depressed.
Barometric Pressure Datum Setting Control and Indicator.	A knob labeled SET IN HG adjusts the barometric pressure datum. The selected datum is displayed on an indicator next to the knob. The datum setting range is from 24.00 to 31.88 inches of mercury.
Wingspan Setting Control and Air-to-Air Mode Knob.	An ON/OFF control, labeled SPAN, pre-selects the air-to-air gun mode when rotated from OFF. Further rotation of the control sets the wingspan of the target for use during stadiametric ranging. The span set is indicated in a window next to the control. A span range of 20 to 120 feet is available.

* Adapted from AV-8A/TAV-8A NATOPS

button is depressed in either cockpit, it overrides TEST 2 selections in the other cockpit. The H preset adjustments are made before flight to harmonize the aiming point. The XG and XY preset adjustments are made before flight to adjust the display. The DIM control knob adjusts the rear cockpit HUD contrast level. This level is then maintained automatically by the rear solar cell unit." (9, p. 283).

D. F-14A (AN/AVQ-12)

The F-14A is a tandem two-seat fighter aircraft. The crew consists of a pilot and a radar intercept officer (RIO).

Control Location and Switch Type

The HUD in the F-14 is part of the Vertical Display Indicator Group (VDIG). The other component of VDIG is a head-down CRT display, the vertical display indicator (VDI). The VDI and HUD simultaneously present mode information to the pilot.

Figure 33 presents a picture of the windscreen that serves as a combiner in the F-14A. Note the reflection of the HUD exit lens on the windscreen. Positioned on the lower starboard instrument console, part of the VDIG control panel can be seen. Figure 34 presents the VDIG control panel, as seen from the pilot's seat in the F-14A.

The VDIG control panel is located on the pilot's starboard instrument console. Both VDI and HUD controls are on this panel. The HUD brightness control, the HUD trim control, and the HUD pitch ladder control, are all rotary switches. The HUD declutter control, the HUD AWL control, and the HUD power switch are all two-position toggle switches. There are 10 pushbuttons located on the panel. Five are for mode selection and five are for submode selection. Only one mode and submode can be selected at a time. When the square pushbutton is depressed, it automatically rotates 90°. This rotation provides the pilot with easy recognition of what mode and/or submode is selected.

Table VII presents the HUD nomenclature and function for the F-14A aircraft (10).

Modes of Operation

The F-14A has five primary modes and five steering command submodes.

1. Primary modes
 - a. Take-off
 - b. Cruise

Table VII

HUD Control Nomenclature and Function for the
F-14A Aircraft^c

Control Nomenclature	Function
HUD BRT control.	Allows pilot to vary HUD brightness.
HUD TRIM control.	Allows pilot to adjust pitch trim on HUD.
HUD AWL switch.	ILS - Selects (AN/SPN-41) display presentation on the HUD during landing phases. ACL - Selects (AN/PSN-42) display presentation on the HUD during landing phases. Normally left in the ACLP position.
HUD DECLUTTER switch.	Placing the switch to ON position reduces the amount of symbology on the HUD. HUD declutter switch can be used in all modes except cruise.
PITCH LAD control.	Controls the position of the pitch ladder on the HUD. To move pitch ladder UP, the control is rotated clockwise. Counterclockwise rotation moves it down.
POWER switches.	Three separate switches are provided for ON-OFF power control of the VDI, HUD, and HSD/ECMD. All three switches must be set to ON to satisfy OBC. In the event of display loss caused by electrical power transients, display may be restored by cycling the appropriate ON-OFF switch.
MODE Pushbuttons	
TO -	Selects takeoff symbology for the HUD and VDI.
CRUISE -	Selects cruise symbology for the HUD and VDI.
A/A -	Selects A/A attack symbology for the HUD and VDI.

**Table VII
(Continued)**

**HUD Control Nomenclature and Function for the
F-14A Aircraft***

Control Nomenclature	Function
A/G -	Selects A/G attack symbology for the HUD and VDI.
LDO -	Selects landing ((LS, ACL) symbology on the HUD and VDI.
STEER CMD Pushbuttons.	
TACAN -	Provides TACAN steering and deviation from the selected TACAN radial.
DEST -	Provides course to selected preset destination point.
AWL/PCD -	Provides glideslope information during landing or precision course direction (vector) information during A/G.
VEC -	Provides D/L deviation steering.
MAN -	Displays manually selected course and heading.

*Adapted from F-14A NATOPS

- c. Air-to-Air
- d. Air-to-Ground
- e. Landing
- 2. Steering command submodes
 - a. TACAN
 - b. Destination
 - c. All Weather Landing/Precision course direction.
 - d. Vector
 - e. Manual

Combination of the primary modes, steering command submodes, and weapon selection yield the following 23 operational modes (Figures 15 through 23):

- a. Take-off/manual (Fig. 15)
- b. Take-off/TACAN (Fig. 15)
- c. Cruise/Vector (Fig. 16)
- d. Cruise/TACAN (Fig. 16)
- e. Cruise/manual (Fig. 17)
- f. Cruise/destination (Fig. 17)
- g. A/A manual gun (Fig. 18)
- h. A/A optical track (Fig. 18)
- i. A/A sidewinder boresight (Fig. 19)
- j. A/A sidewinder NORMAL (Fig. 19)
- k. A/A Phoenix boresight (Fig. 20)
- l. A/A Phoenix normal (Fig. 20)
- m. A/A SPARROW boresight (Fig. 21)

- n. A/A SPARROW normal (Fig. 21)
- o. A/G Computer-Initial Point (Fig. 22)
- p. A/G Computer - Target (Fig. 22)
- q. A/G Precision Course Direction (Fig. 23)
- r. A/G Computer-Pilot (Bomb) (Fig. 23)
- s. A/G Computer-Pilot (Guns, Rockets) (Fig. 24)
- t. A/G Manual (Fig. 25)
- u. Landing/Vector (Fig. 25)
- v. Landing/All Weather Landing (Fig. 26)
- w. Landing/TACAN (Fig. 26).

Other HUD Inputs

Inputs into the inertial navigation system or weapons selection by the pilot influences what is depicted on the HUD. HUD test modes are initiated when INST is selected on the master test panel.

E. GENERAL COMMENTS

Further detailed information on pilot inputs to the HUD units are available from the tactical manual for each aircraft. Classified portions of this information are not included in this report.

The modes of the operation available to the pilot vary considerably from aircraft to aircraft. This can be explained partly in terms of the missions of the different aircraft (i.e., attack, V/STOL, fighter). The modes specified in MIL-D-81841 (AS) are as follows:

1. Takeoff/Navigation
2. Terrain Following
3. Bombing
4. Boresight Weapons
5. Guided Weapons

6. Landing
7. Test
8. Boreight
9. Standby

The terrain-following mode is optional for both attack and fighter aircraft, bombing mode is optional for fighter aircraft, and Guided Weapons mode is optional for attack aircraft. According to MIL-D-81841 (AS), "Modes such as Bombing, Boreight Weapons, and Non-Boreight missiles may have submodes which should be designated by the detailed specifications of the HUD for a particular aircraft." (8, p. 11).

MIL-D-81841 (AS) also lists the manual control to be provided on the HUD control panel. These controls are:

1. Symbol Brightness/ON
2. Mode Selectors
3. Submode Selection
4. HUD Barometric/Radar Altitude Selection
5. Barometric Altitude Adjustment
6. VAM Selection (vertical velocity/airspeed/mach number).
7. Scales on/off
8. Filter
9. Standby Reticle Brightness
10. Standby Reticle MIL Depression
11. Standby Reticle Filament Selection
12. Camera on/off
13. HUD Control Panel Lights Switch

As can be noted from the previous sections, none of the aircraft has a HUD control panel that conforms to the military specification for HUDs. Accord-

ing to MIL-D-81841 (AS), the HUD control panel is to be located on the starboard side of the cockpit. Only the F-14A aircraft meets this specification.

Although all the manual HUD controls are clearly labeled, the pilot is required to bring his eyes back "into" the cockpit to ensure proper switch selection. Controls located on the side of the HUD unit, such as in the A-4M, are at best difficult to read. However, informal interviews with A-4M, A-7E, AV-8A, and F-14A pilots indicate that the pilots do not consider the HUD control panels a problem area. All pilots interviewed felt that the panels were easy to use, and there was little likelihood of inadvertent control activation or control confusion. Computer inputs to the HUDs are typically accomplished on the deck prior to taxi. Rarely are inputs to the HUD via the computer entered in flight. Overall, the workload requirements for computer input and mode selection are minimal and are not considered a detriment to mission performance.

IV. SUMMARY

Operational HUDs were found to differ significantly from each other and from the military specification for HUDs, MIL-D-81841 (AS), with respect to symbology and formatting. Furthermore, display clutter was reported by pilots to be a major problem. A comprehensive information processing evaluation of virtual image symbols and formatting under dynamic display conditions is recommended.

None of the current aircraft has a HUD control panel that complies to MIL-D-81841 (AS), the military specification for HUDs. Pilots are required to bring their eyes back "into" the cockpit to ensure proper switch selection and, consequently, negate the primary purpose of maintaining a head-up mode.

REFERENCES

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2. AV-8A COCKPIT SYSTEMS. Report Number MDC A3135. McDonnell Aircraft Corporation, Saint Louis, Missouri, 30 May 1975.
3. Egan, D. E., and Goodson, J. E. Human factor engineering for head-up displays: A review of military specifications and recommendations for research. NAMRL Monograph 23. Naval Aerospace Medical Research Laboratory, Pensacola, Florida, April 1978.
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6. MIL-D-81641(AS): Display, head-up, general specification for. 20 June 1972.
7. NATOPS FLIGHT MANUAL AV-8A Aircraft: NAVAIR 01-AV8A-1, 1 June 1976.
8. NATOPS FLIGHT MANUAL A-4M Aircraft: NAVAIR 01-40, changed 1 May 1976.
9. NATOPS FLIGHT MANUAL A-7C, A-7E Aircraft: NAVAIR 01-45AAE-1 changed 1 March 1973.
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13. Smith Industries Military Head-up Display System. TSP 2199. Smith Industries Limited, Bishops Cleeve, Cheltenham, Gloucestershire, January 1971.
14. TAV-8A cockpit systems. Report Number MDC A3237. McDonnell Aircraft Company, Saint Louis, Missouri, 31 May 1975.

15. Vertical Display Indicator Group (VDIG) AN/AVQ-12 Design Control Specification for F-14A Weapon System. Specification No. A51 OCVAD 00413, Grumman Aerospace Corporation, Bethpage, L. I., New York, 18 November 1974.

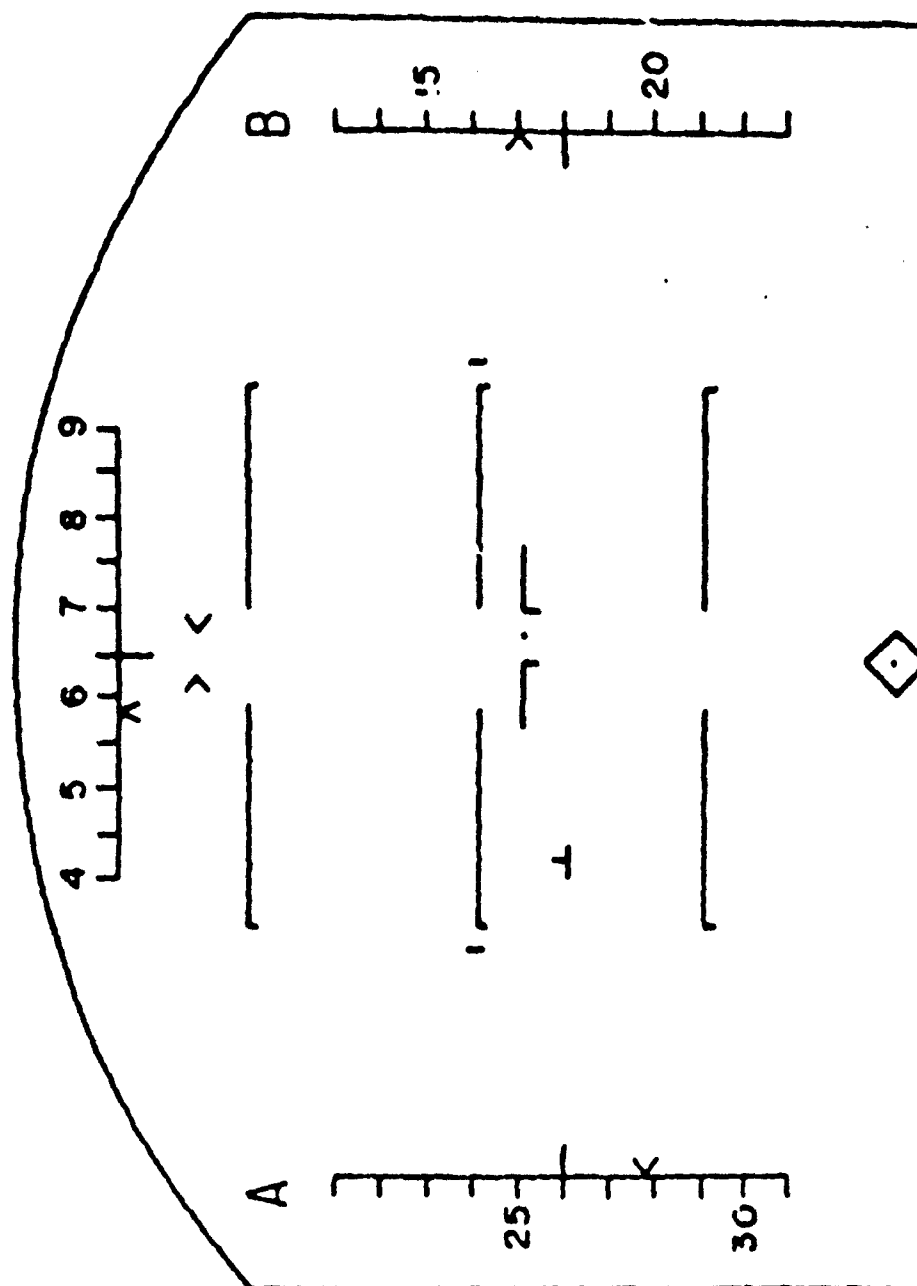


Figure 1. Take-off/Navigation Mode, as specified in MIL-D-81641 (AS)

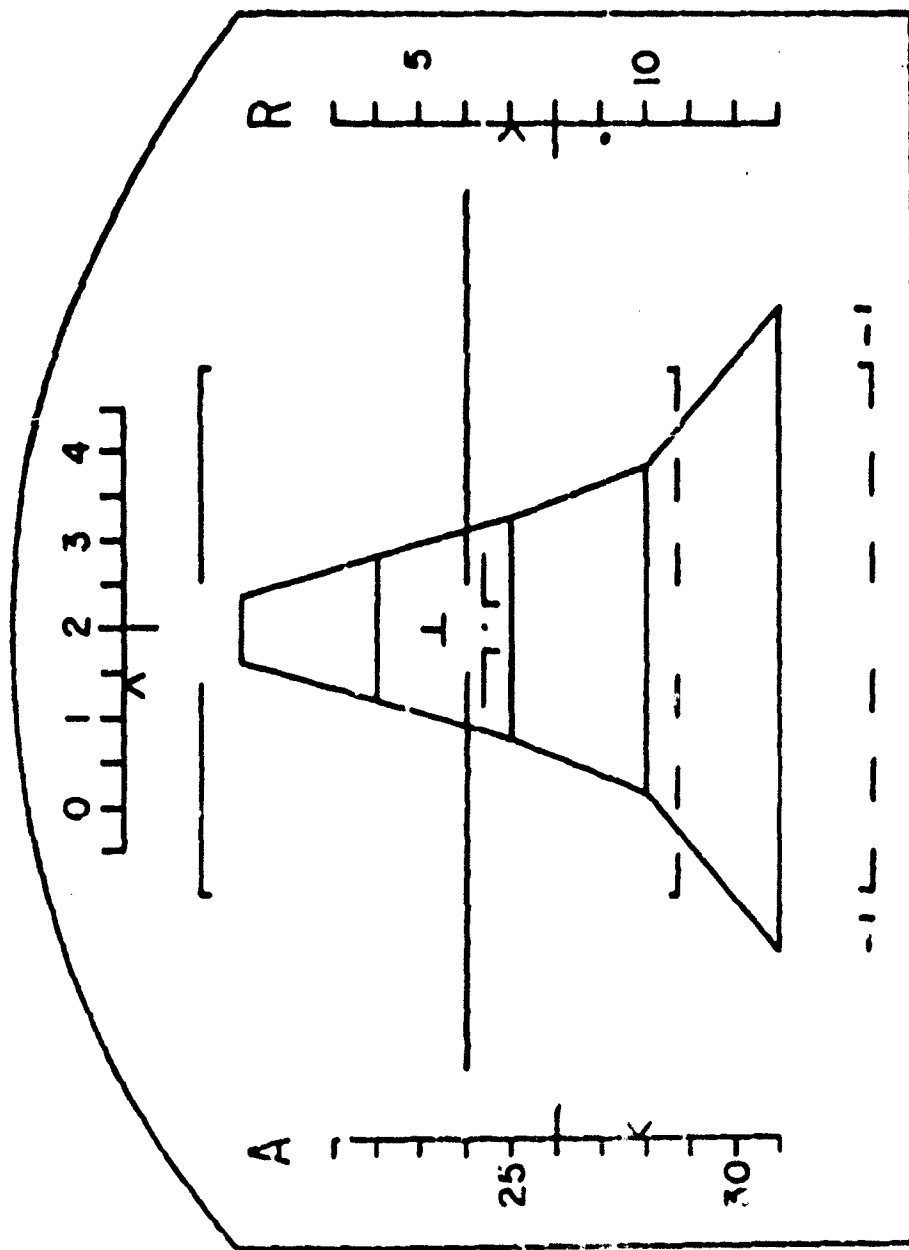


Figure 2. Terrain Following Mode, as specified in MIL-D-81641 (AS)

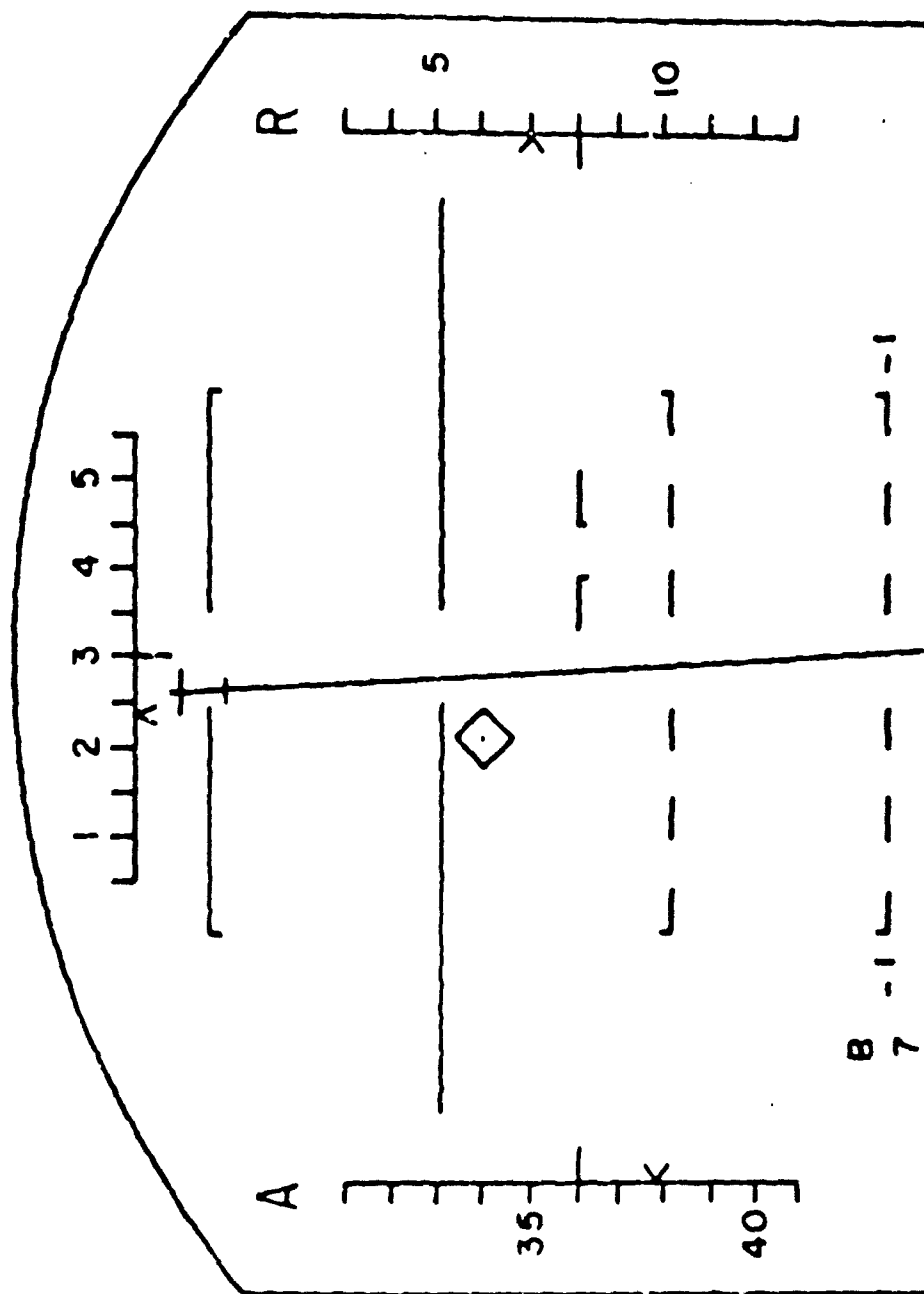


Figure 3. Bombing Mode, as specified in MIL-D-81841 (AS)

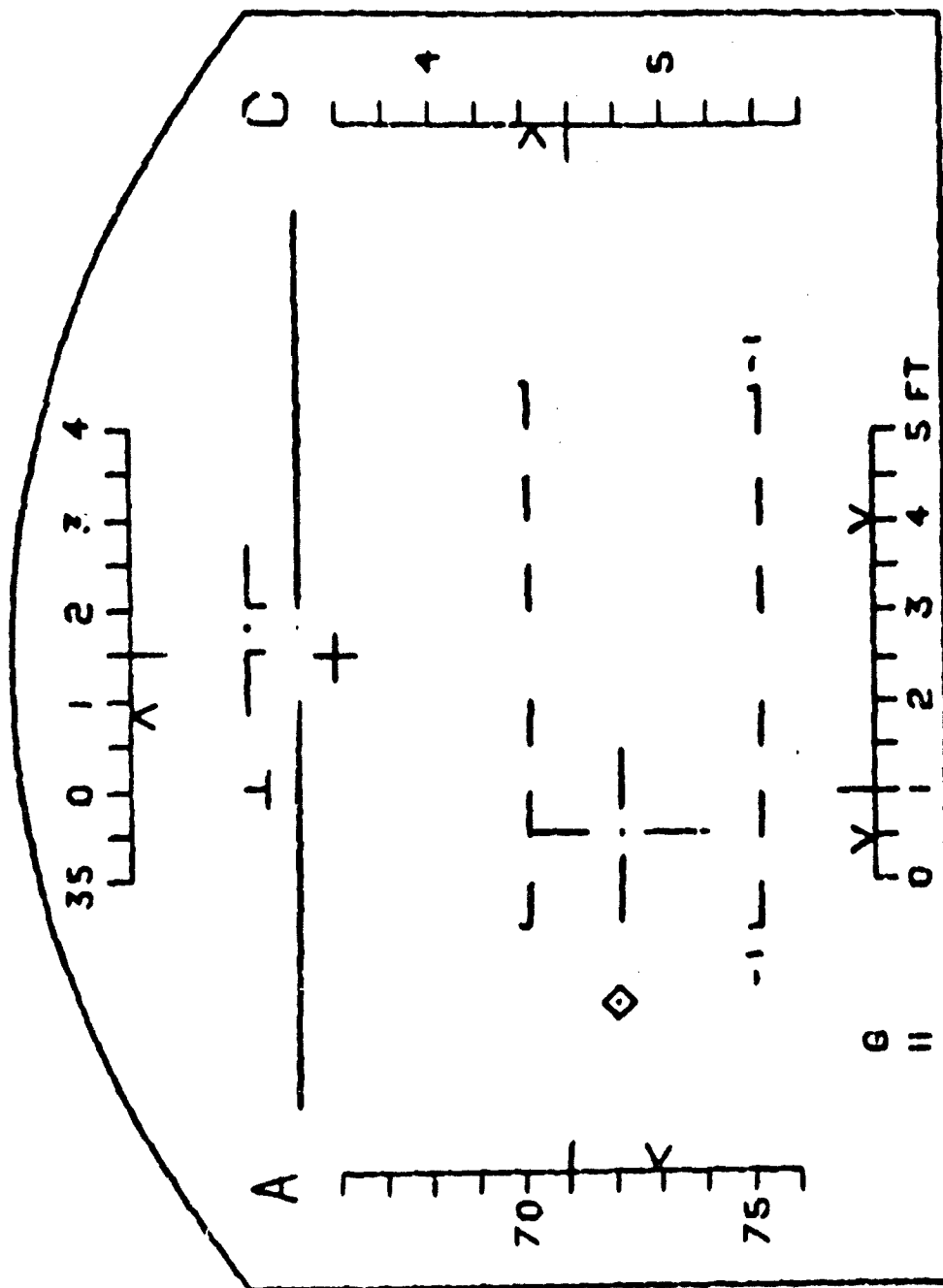


Figure 4. Bore-sight Weapon Mode, as specified in MIL-D-1341 (AS)

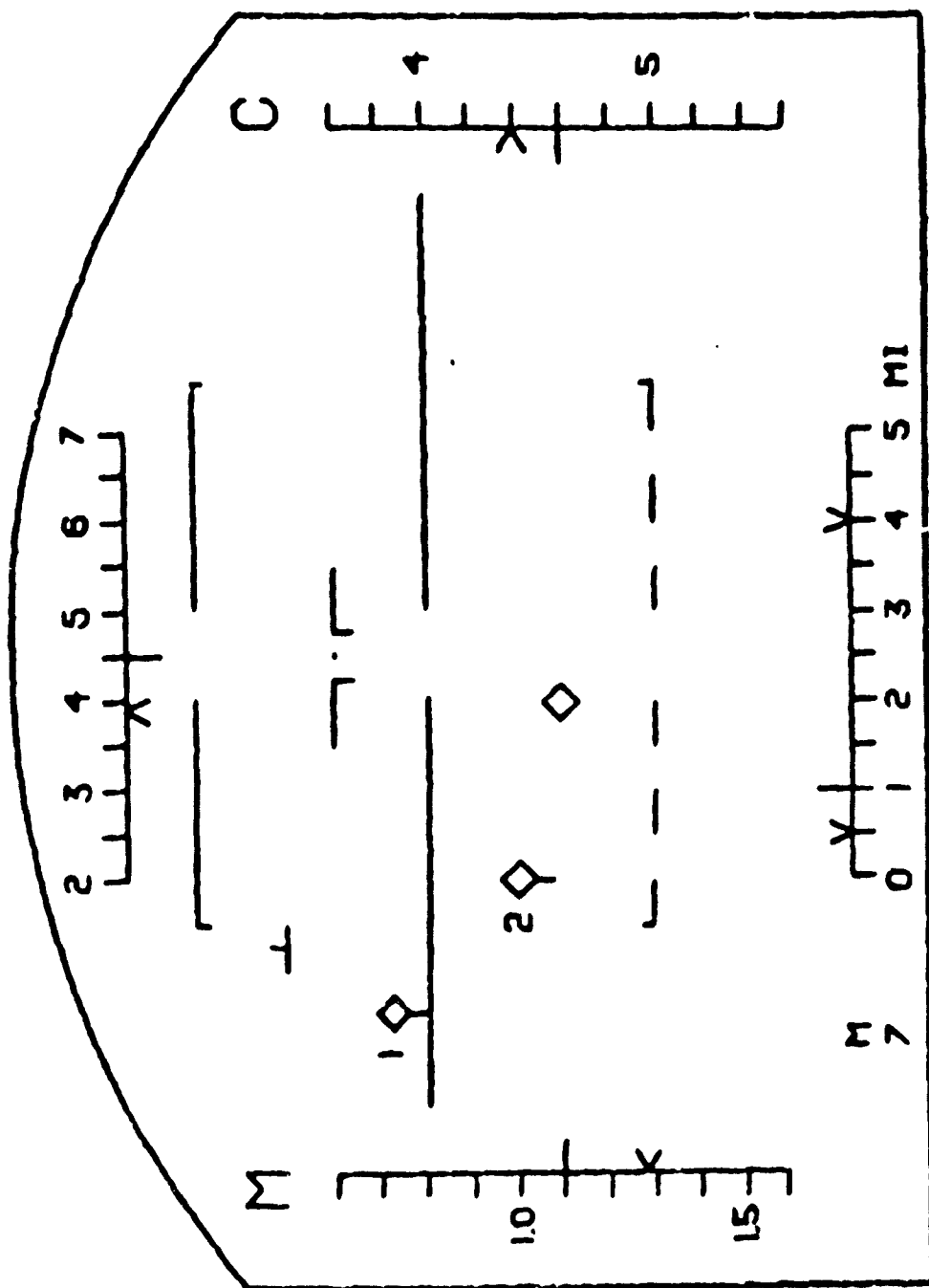


Figure 5. Guided Weapons Mode, as specified in MIL-D-81641 (AS)

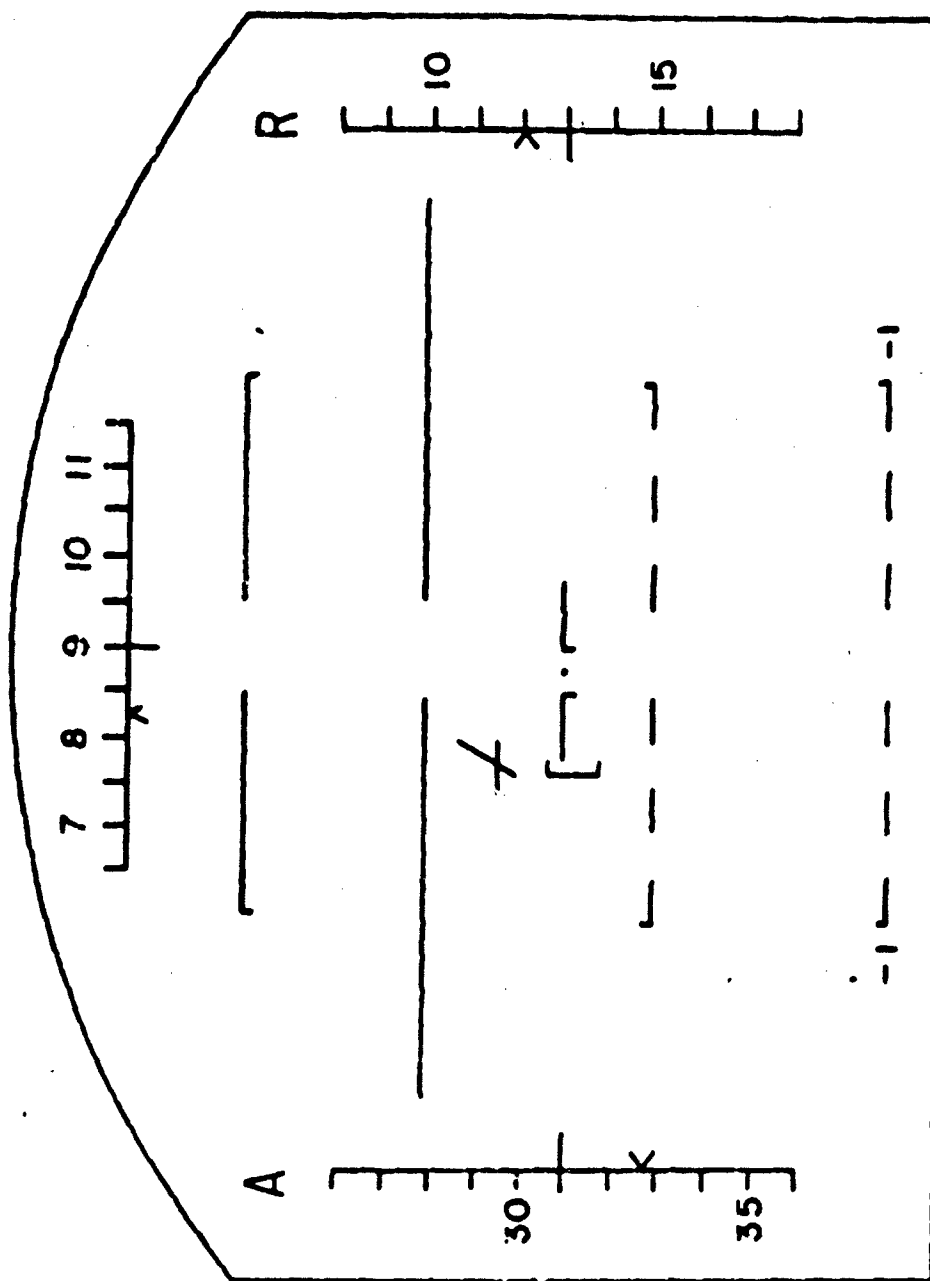


Figure 6. Landing Mode, as specified in MIL-D-81641 (AS)

E - BAROMETRIC ALTITUDE, RADAR ALTITUDE, AND CLOSURE RATE
V - ORDNANCE TYPE AND NUMBER
C - WARNING INDICATOR

B - HEADING
C - FULL UP
D - LANCE

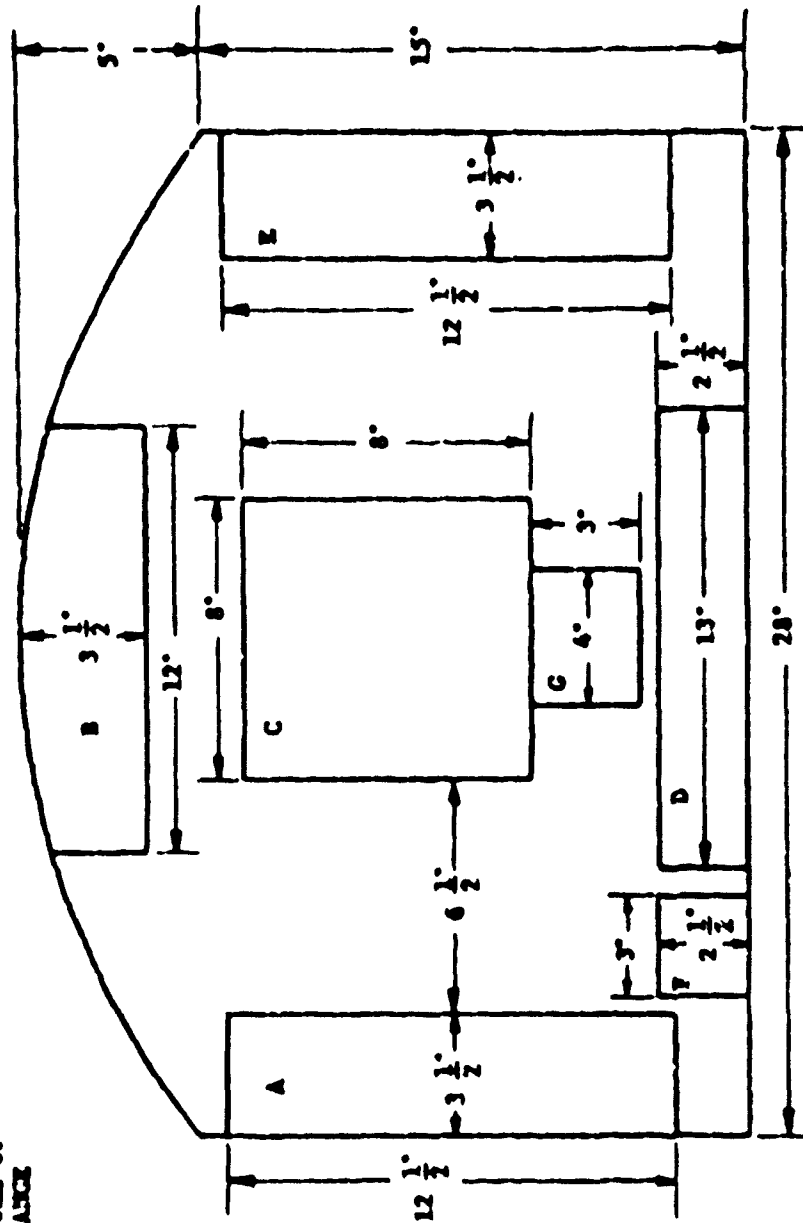


Figure 7. Field of view and fixed location symbol positions. as specified in MIL-D-81841 (AS)

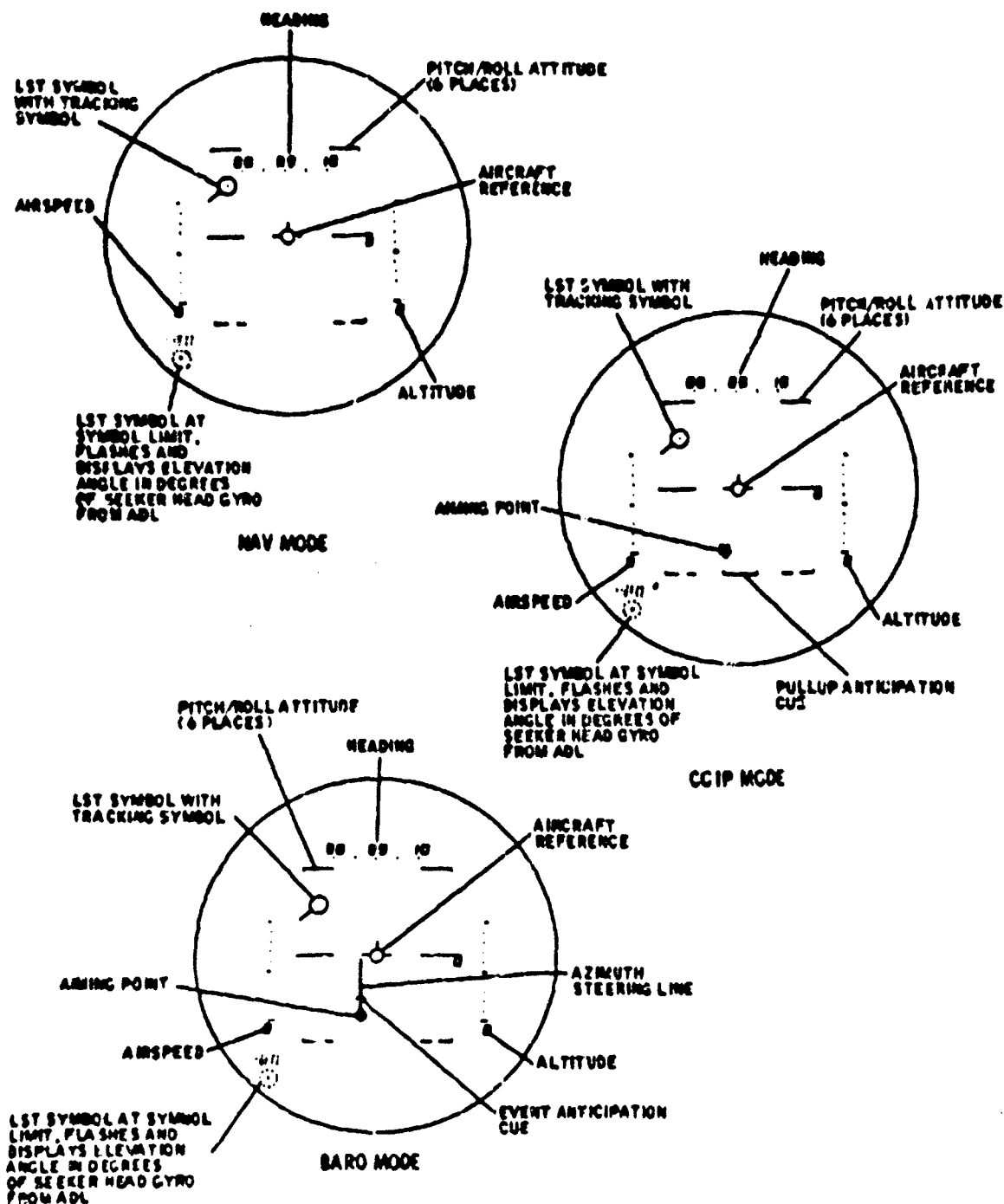


Figure 8. A-4M Display Modes

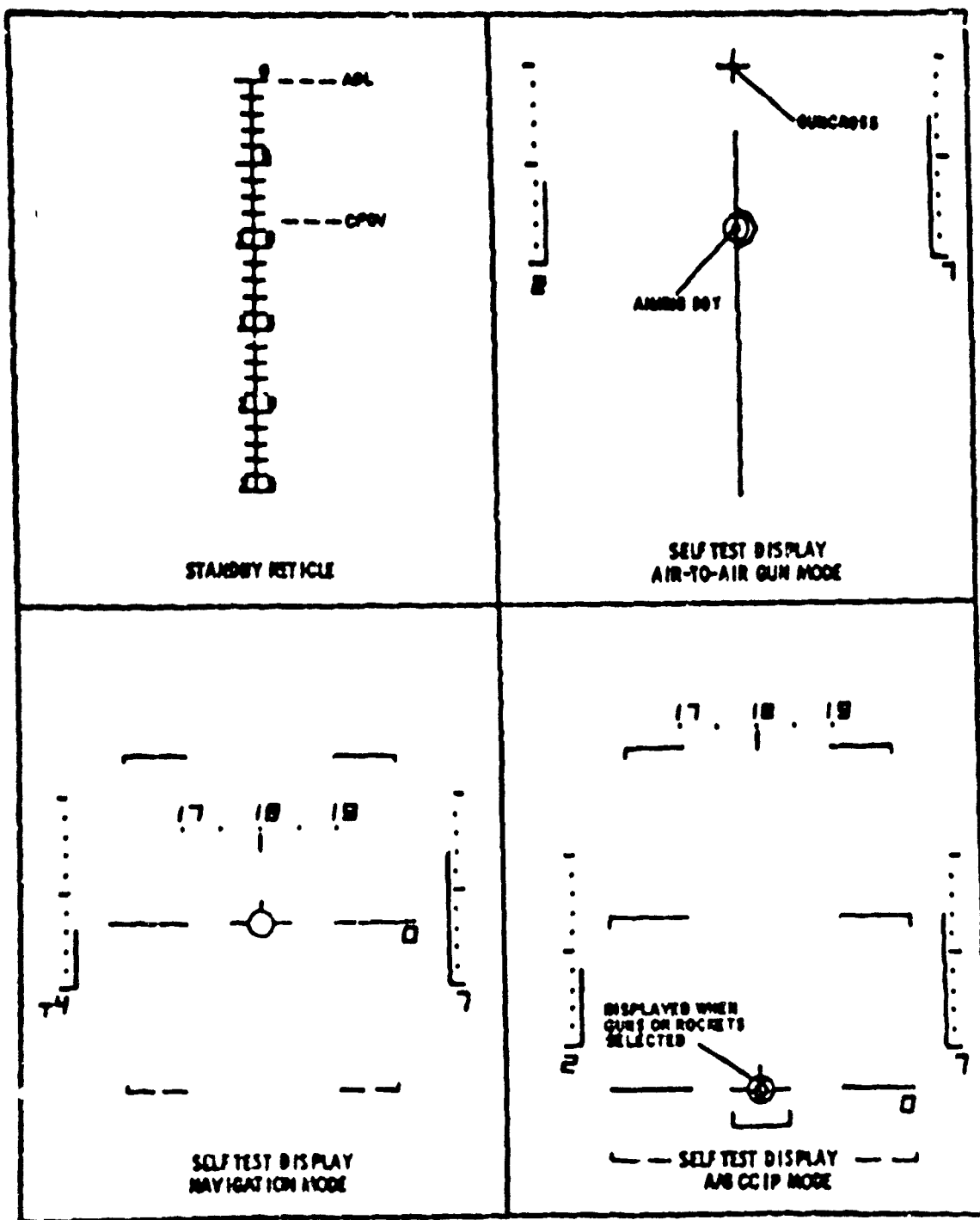


Figure 8. A-4M Test Modes

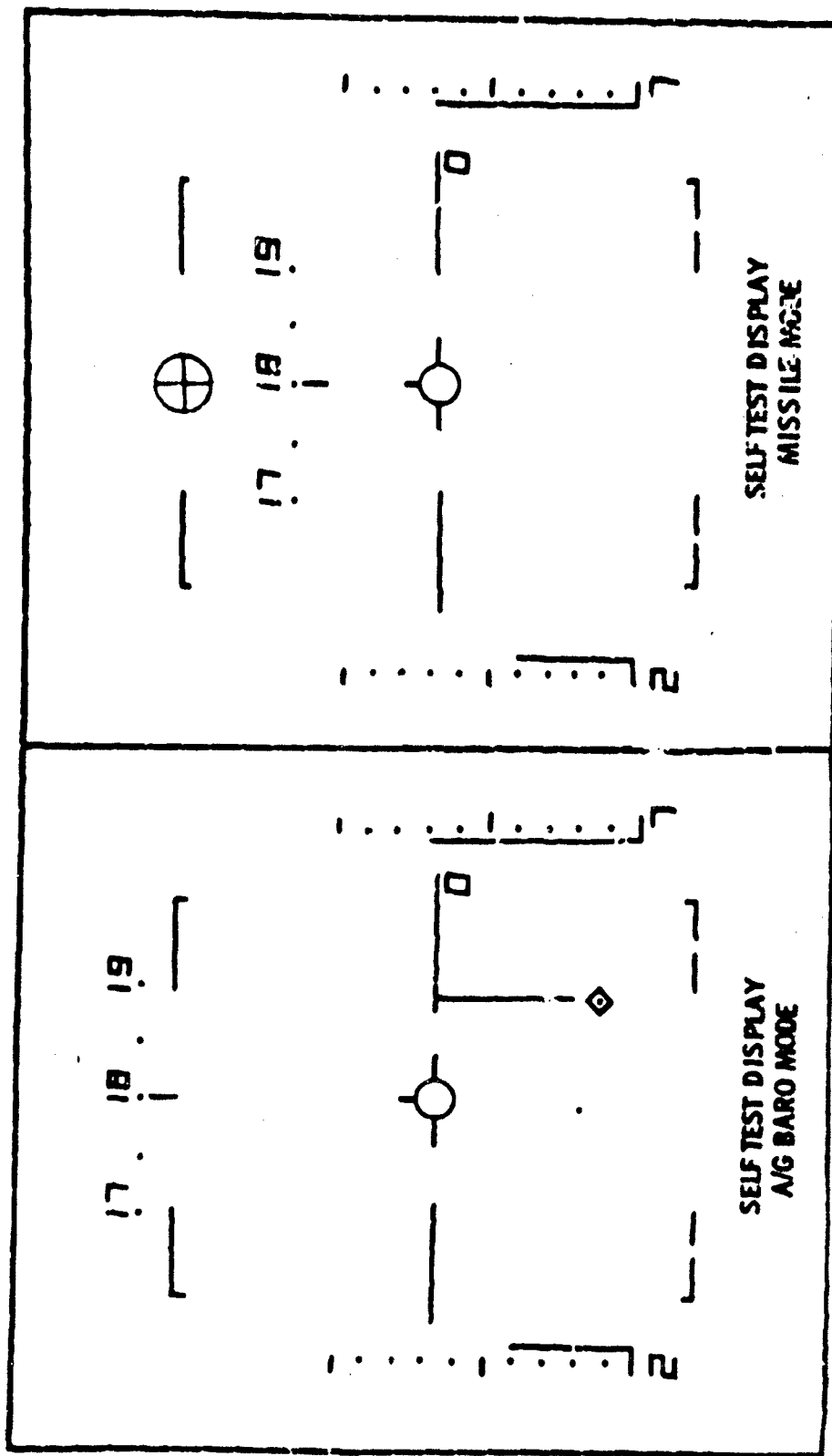
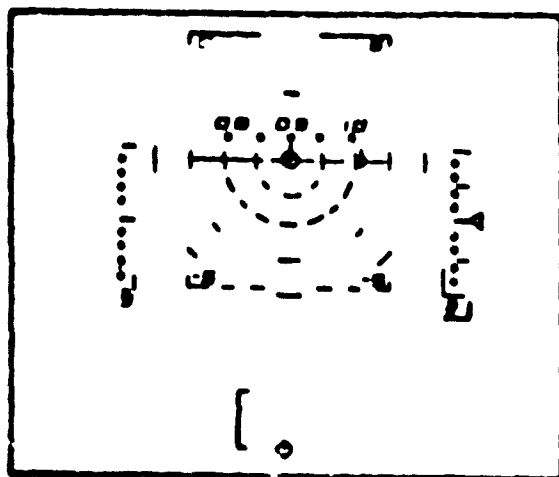
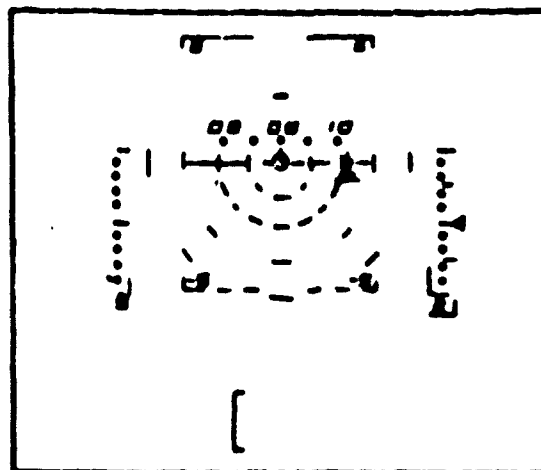


Figure 10. A-4M Test Modes



ENROUTE ON TX MODE
WITH STANDBY RETICLE
(RDR ALT selected)



LOS OR DATA LINK MODE
WITH STANDBY RETICLE
(RDR ALT selected)

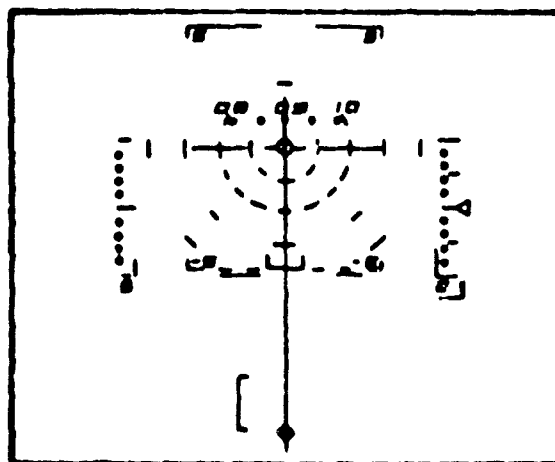


Figure 11. A-7E Display Modes

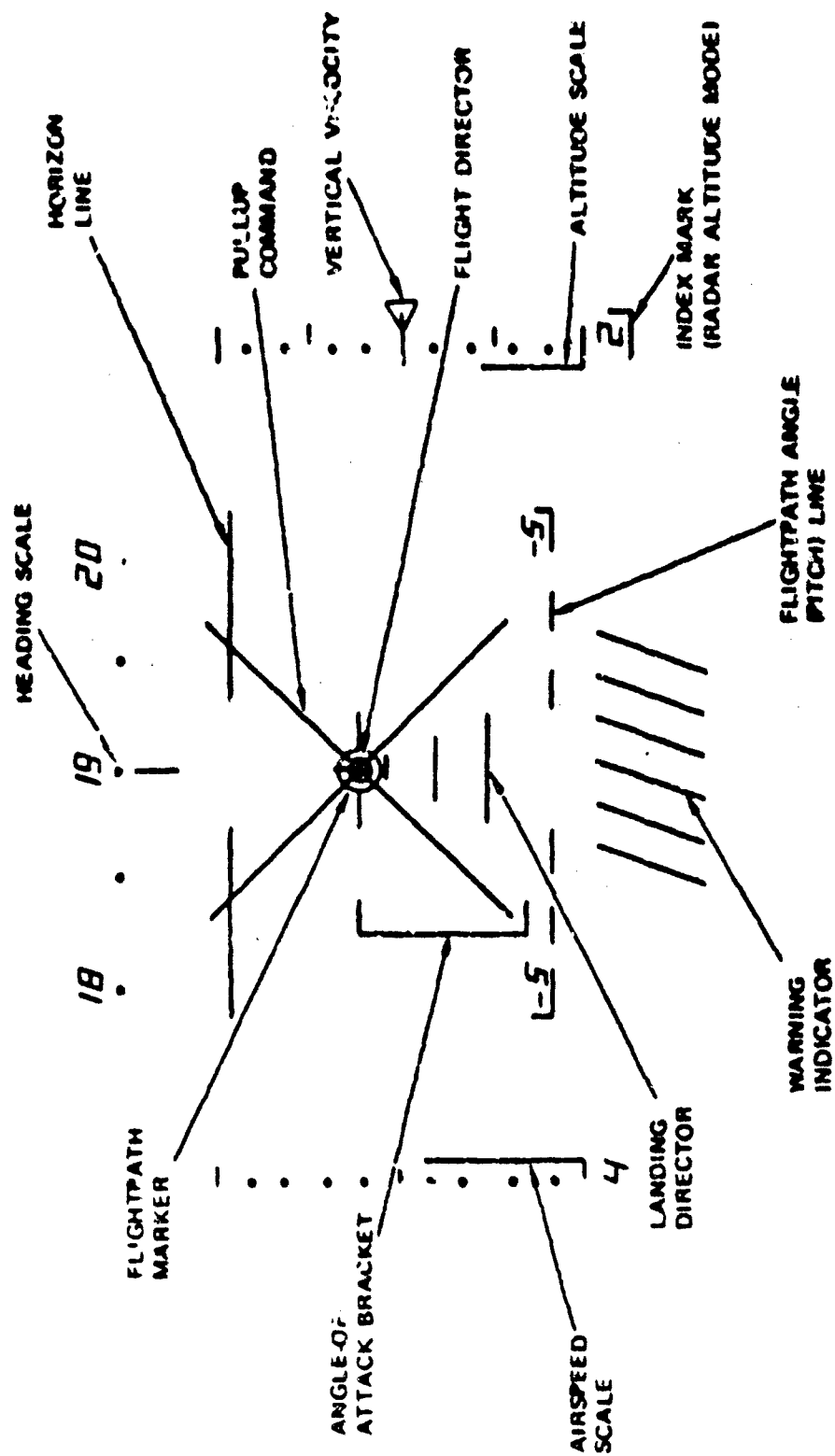


Figure 12. A-7E Display Format

MODE DISPLAYS

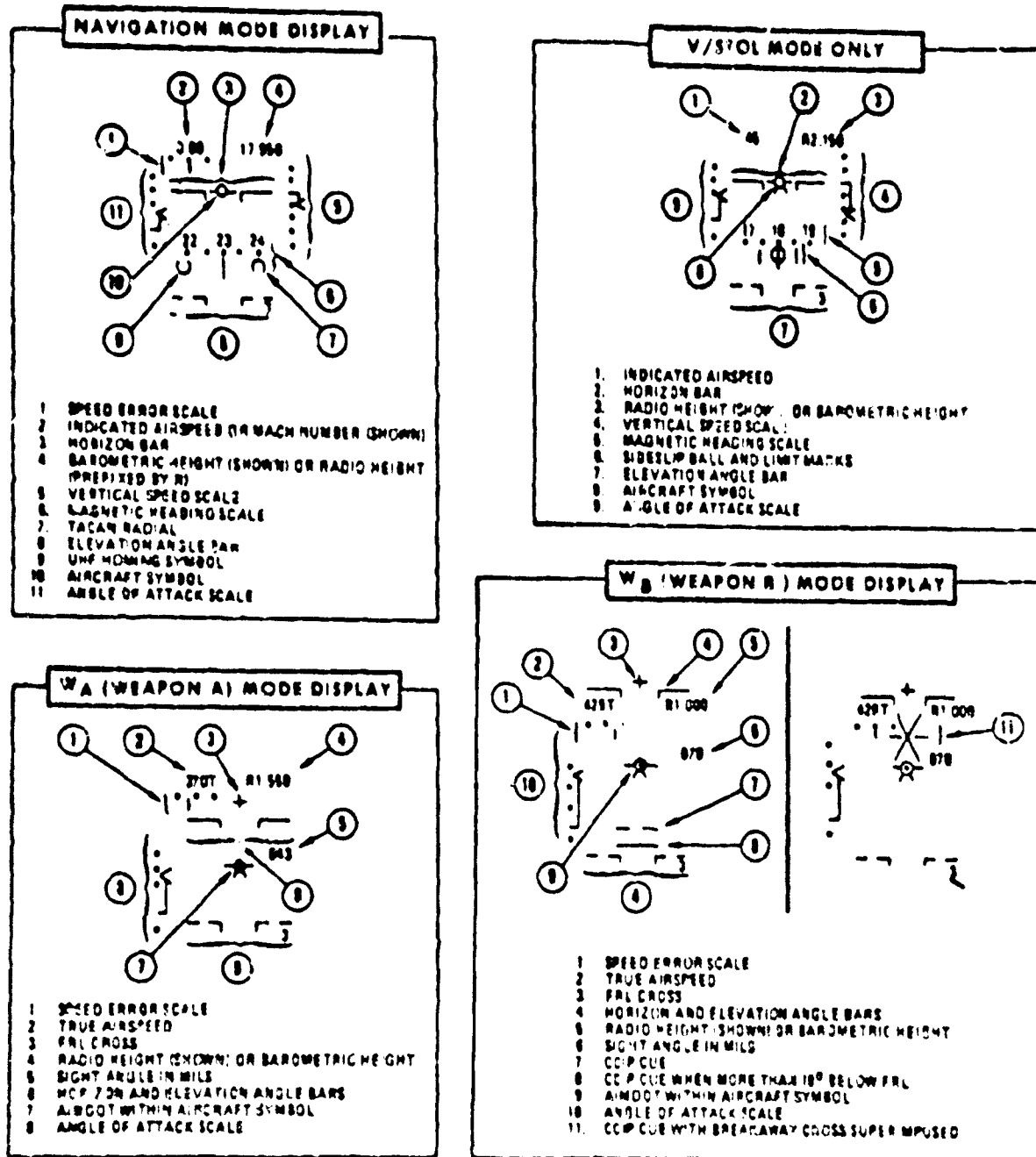
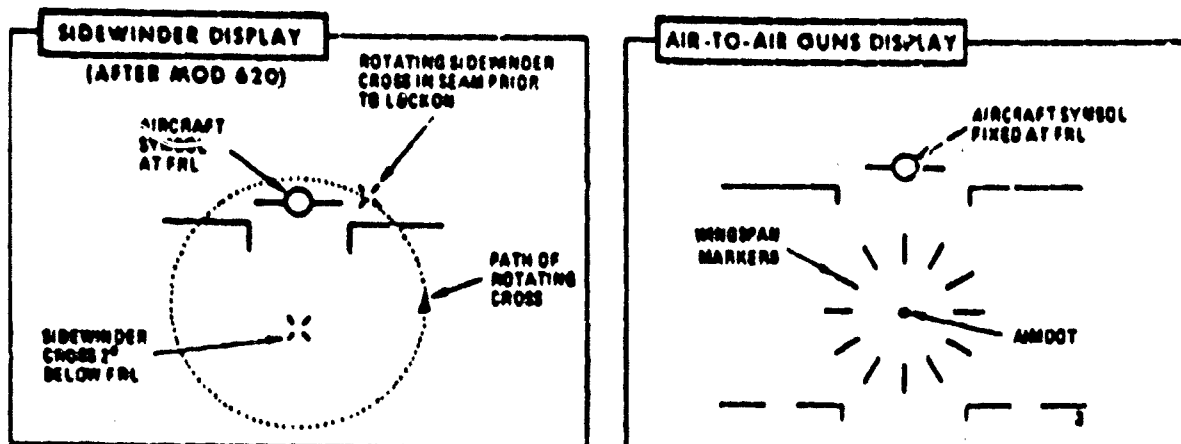


Figure 13. AV-8A Display Modes

MODE DISPLAYS



BIT DISPLAYS

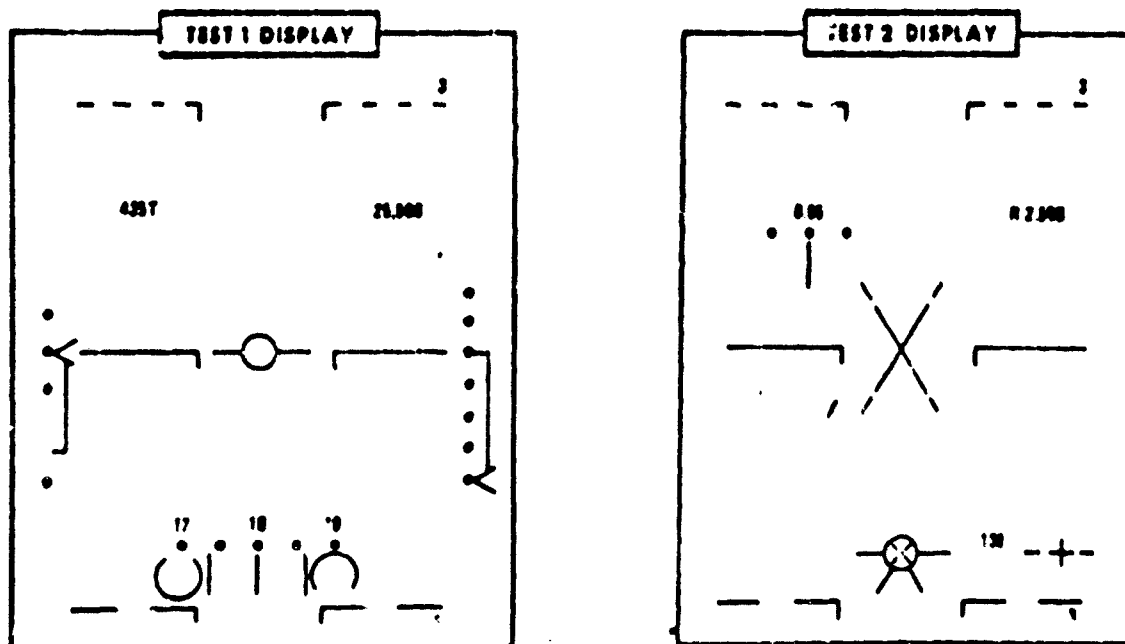
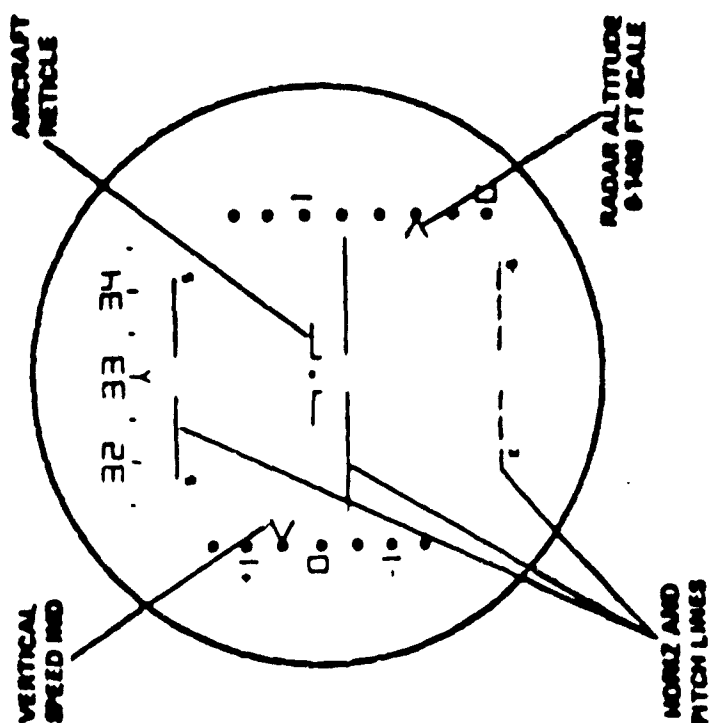


Figure 14. AV-8A Display and Test Modes

TAKE-OFF MODE/MANUAL SUBMODE



TAKE-OFF MODE/TACAN SUBMODE

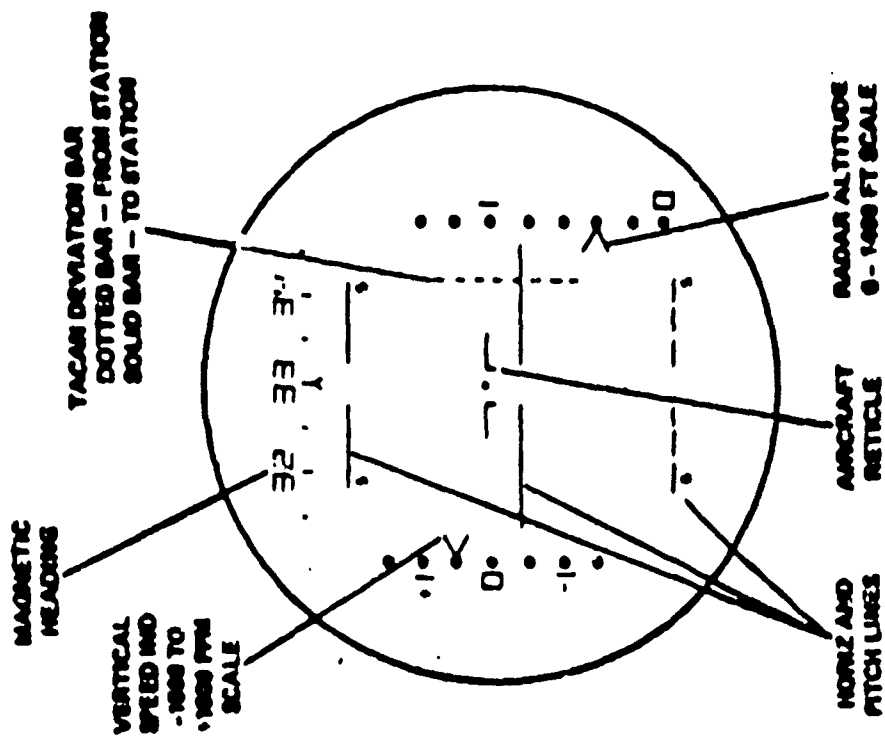


Figure 15. F-14A Display Modes

CRUISE MODE/VECTOR SUBMODE

CRUISE MODE/TACAN SUBMODE

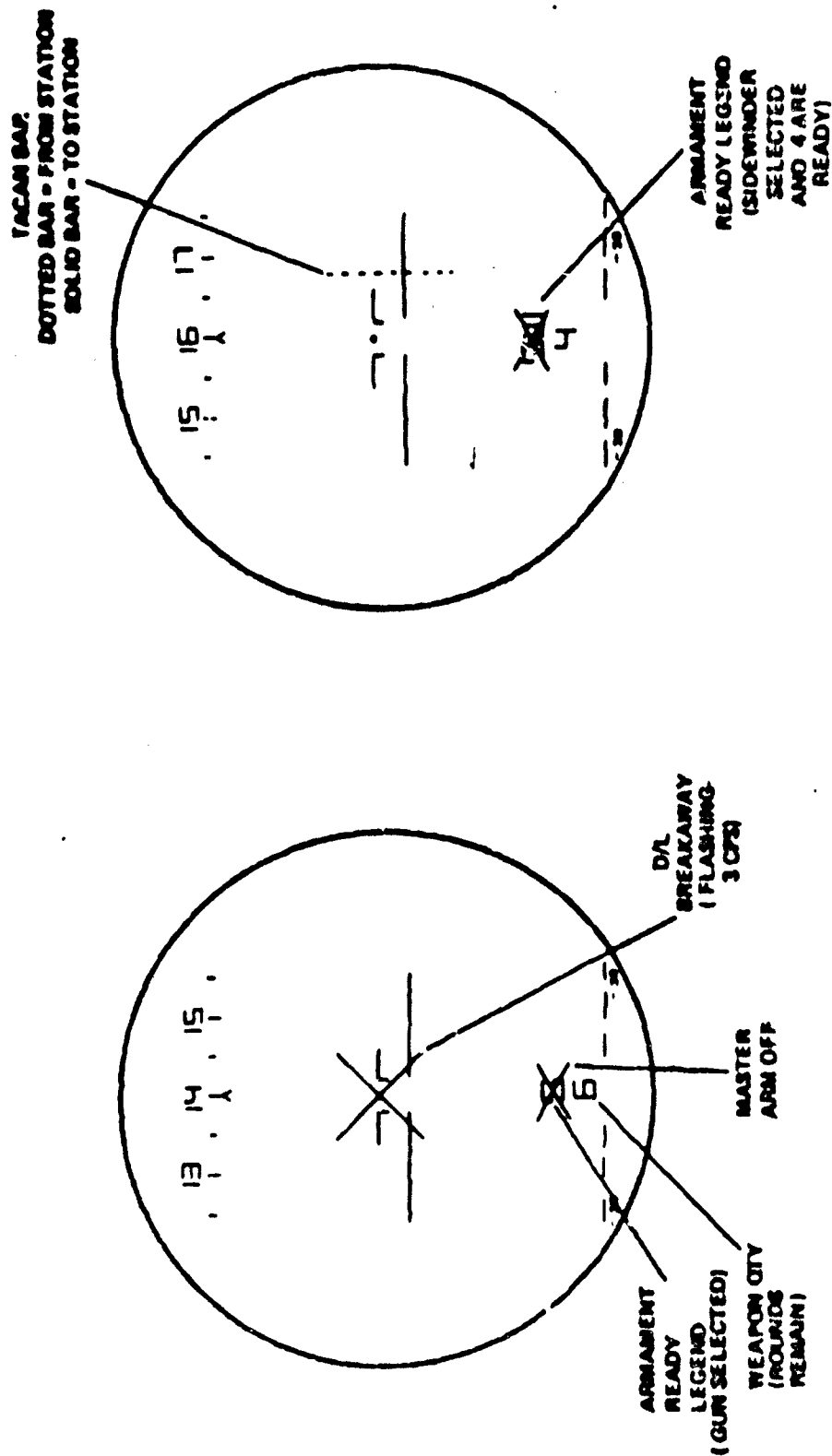


Figure 15. F-14A Display Modes

CRUISE MODE/MANUAL SUBMODE

CRUISE MODE/DESTINATION SUBMODE

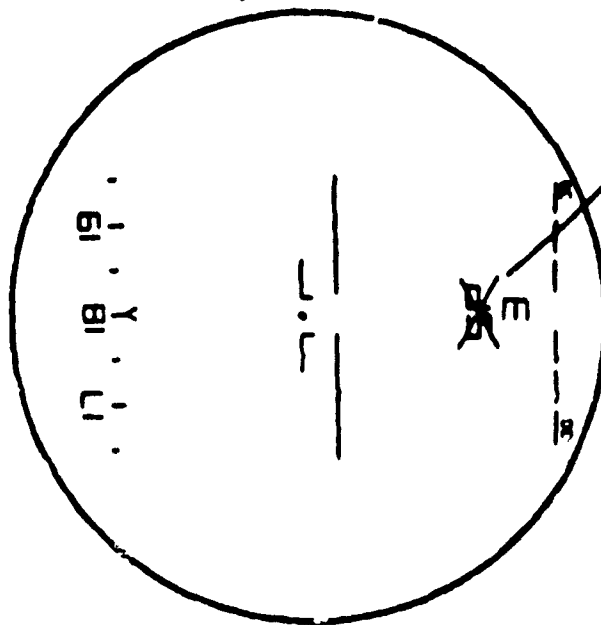
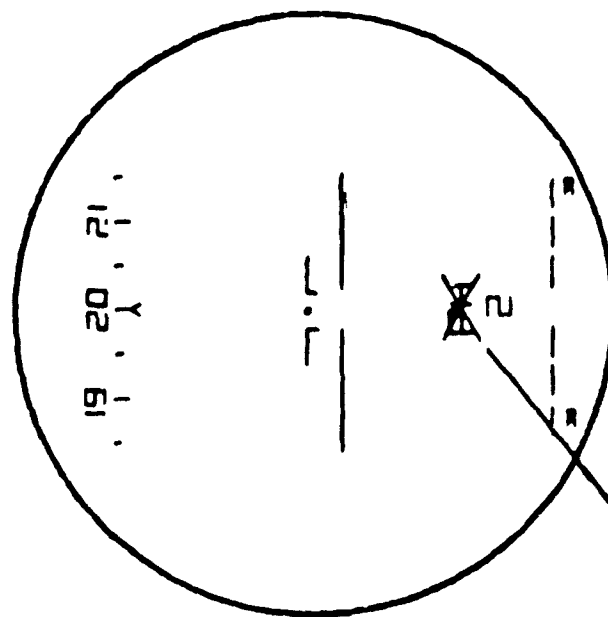


Figure 18. F-14A Display Modes

RTGS HUD DISPLAYS

A/A MANUAL GUN MODE

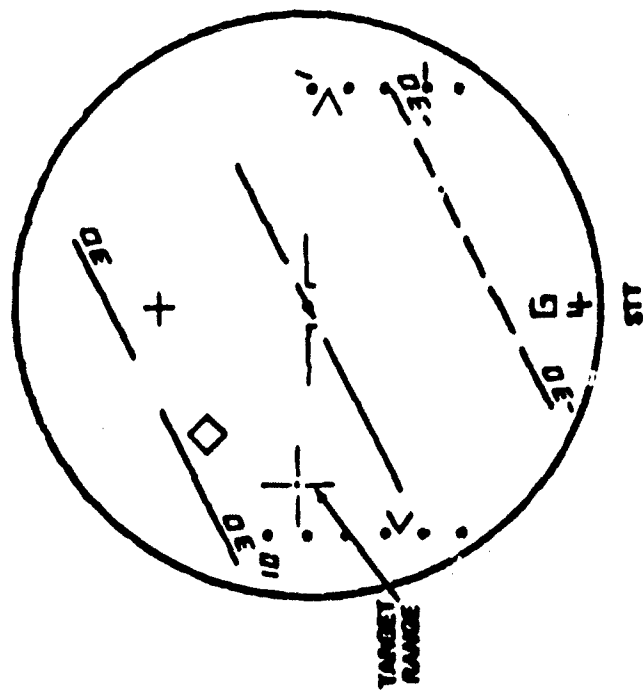
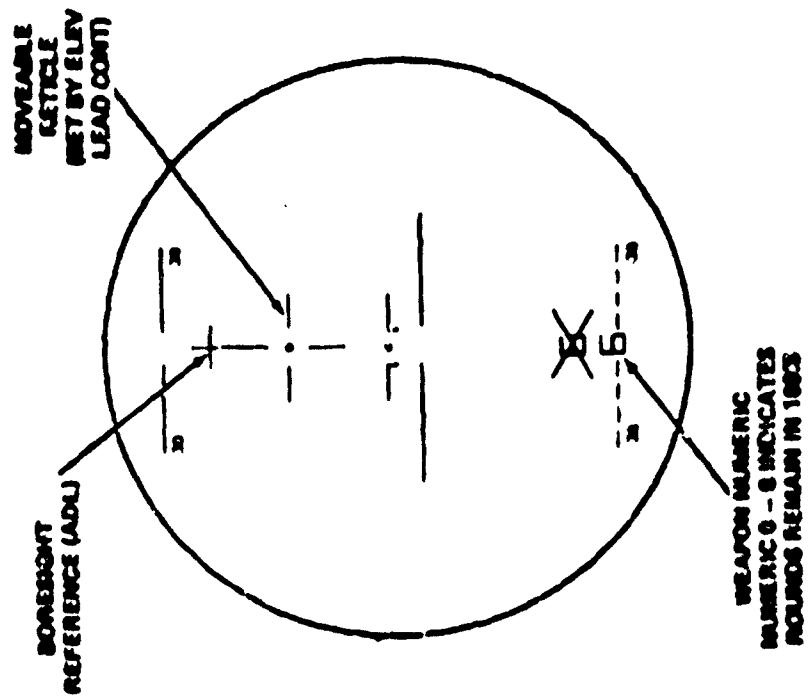
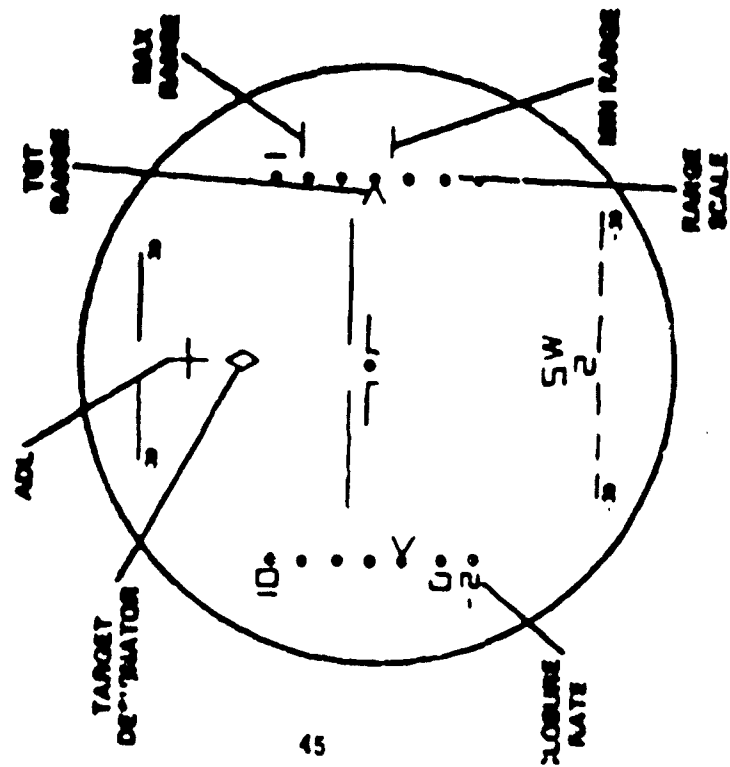


Figure 17. F-14A Display Modes

A/A SIDEWINDER DOWNSIGHT MODE



A/A SIDEWINDER NORMAL MODE

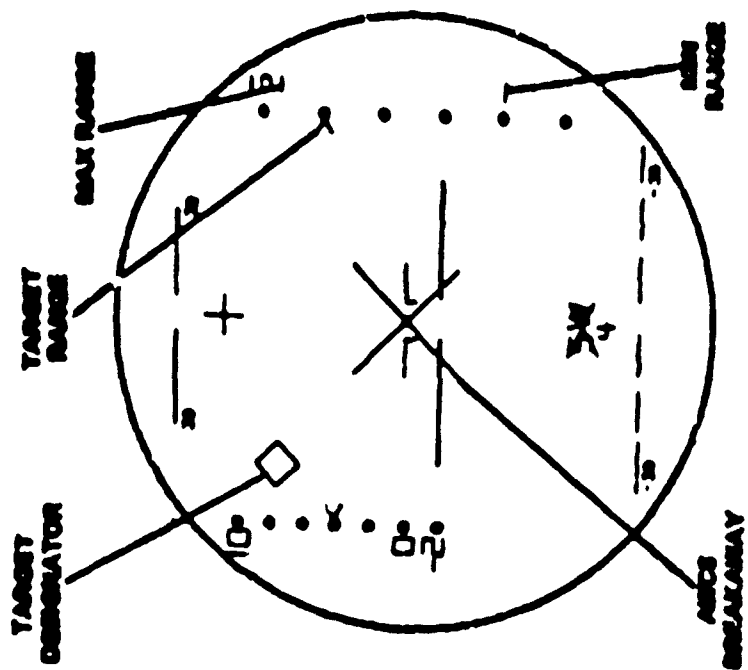


Figure 16. F-14A Display Modes

A/A PHOENIX BORESIGHT MODE

A/A PHOENIX NORMAL MODE

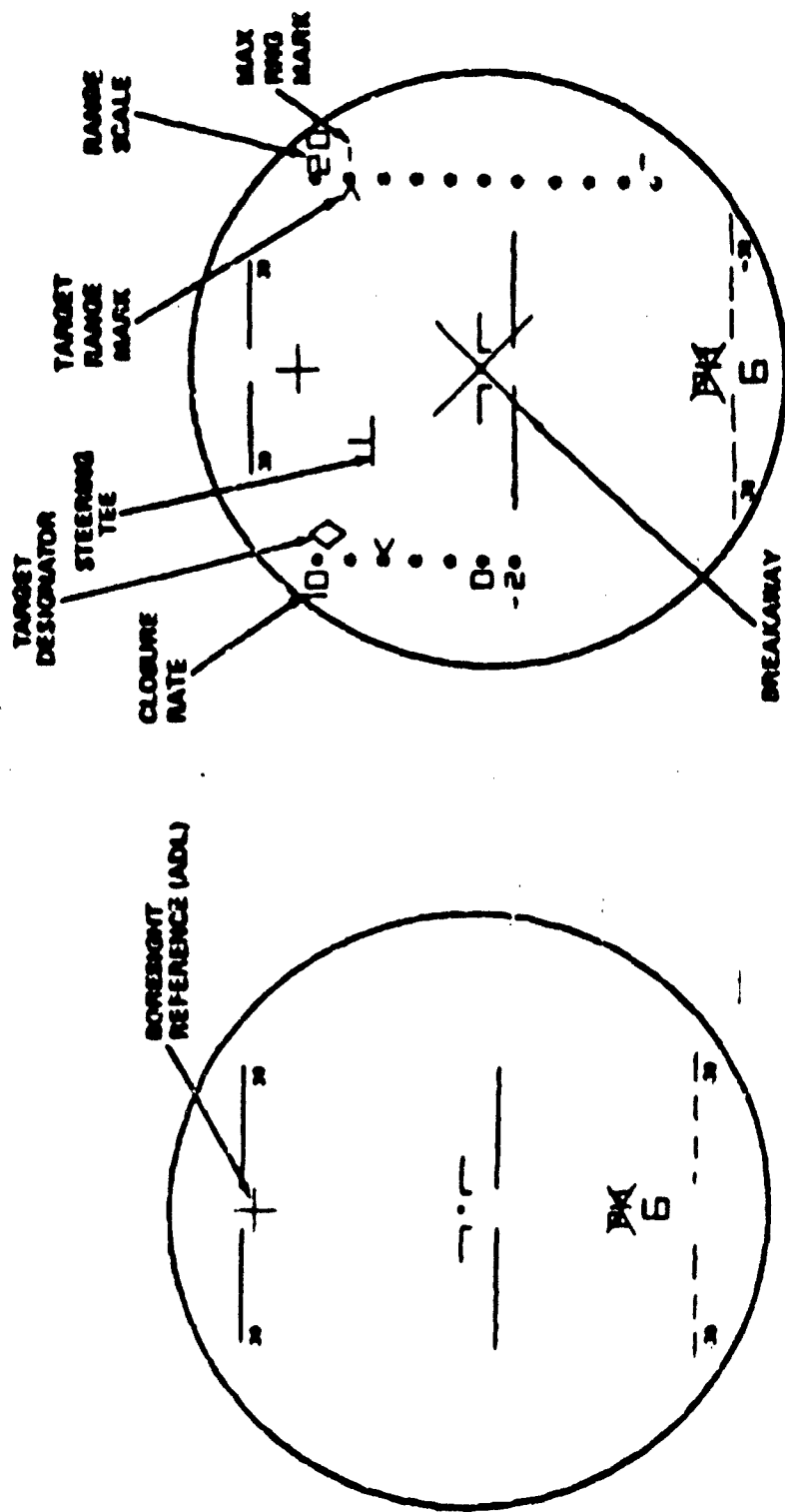


Figure 19. F-14A Display Moles

SPARROW NORMAL MODE

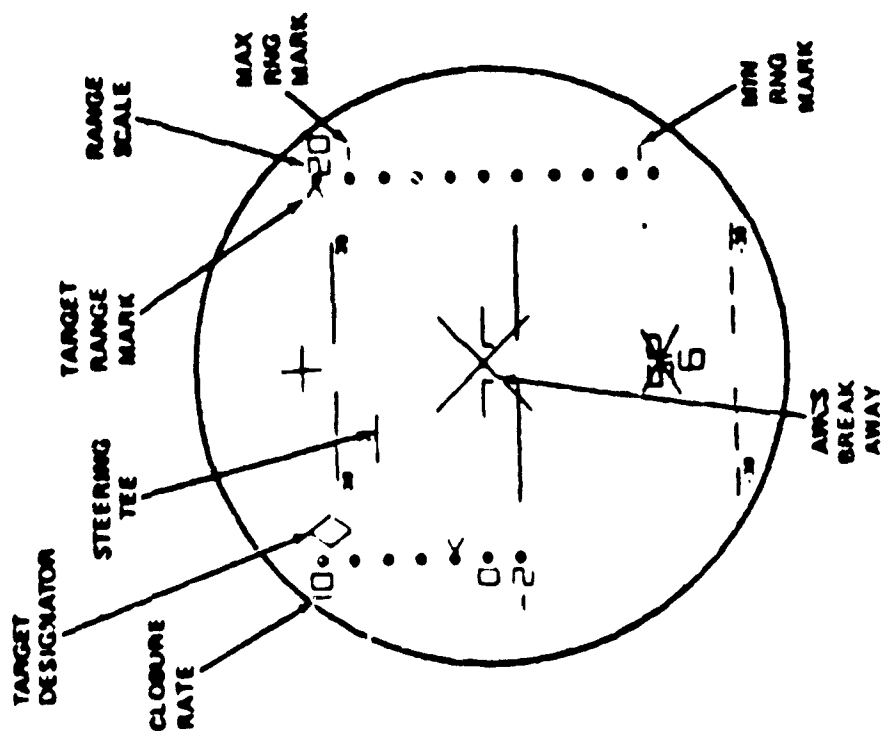
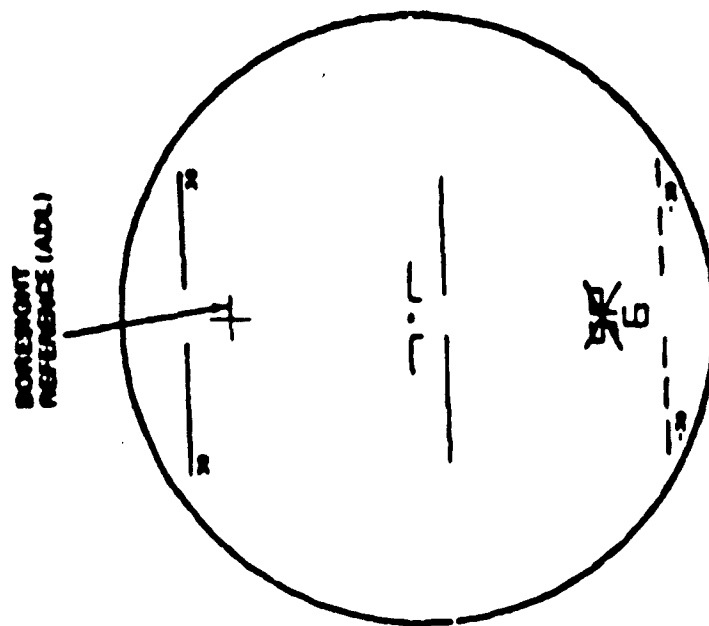


Figure 20. F-14A Display Modes

A/A SPARROW BORESIGHT MODE



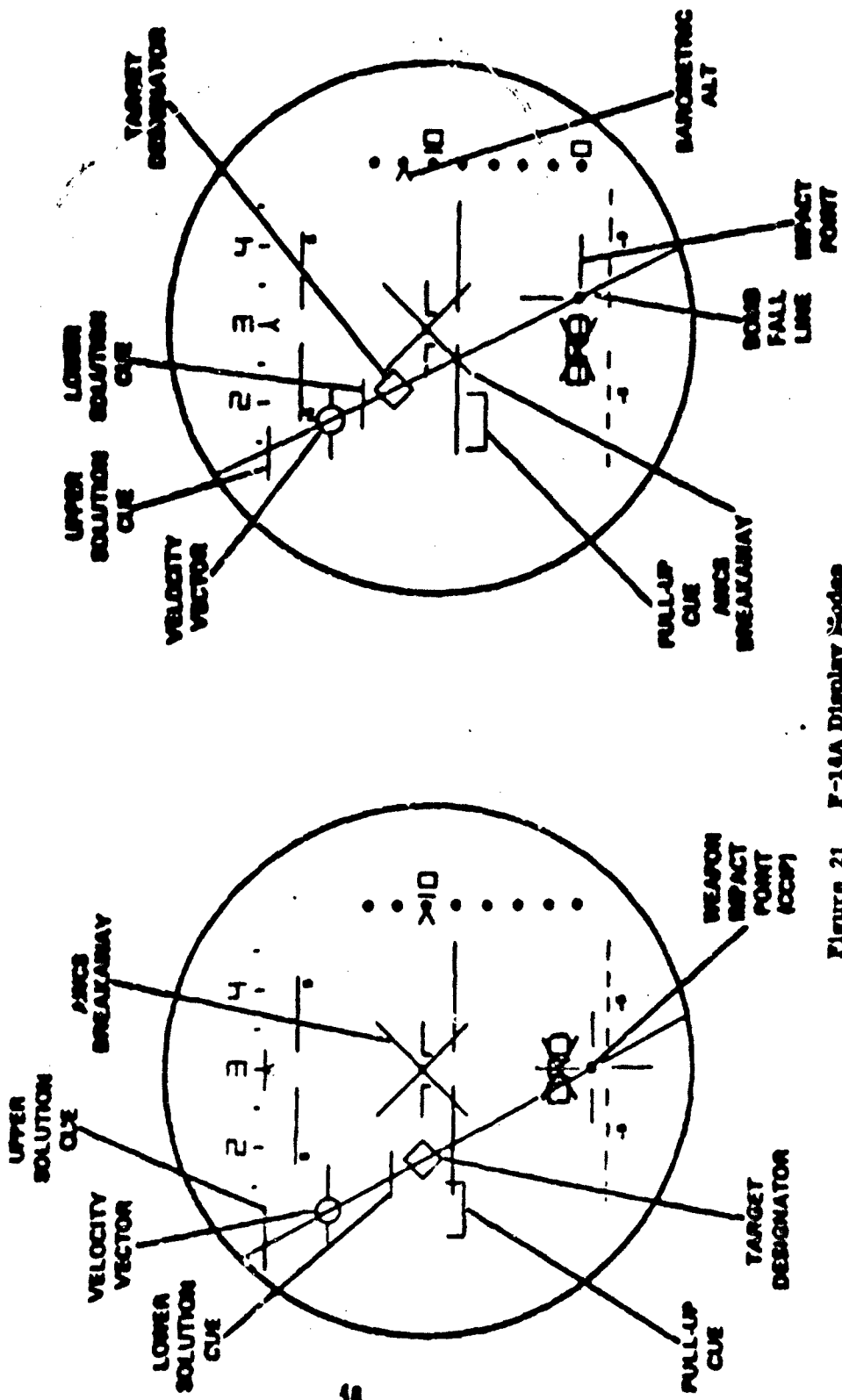


Figure 21. F-14A Display Modes

A/G PCD MODE

A/G COMPUTER-PILOT MODE

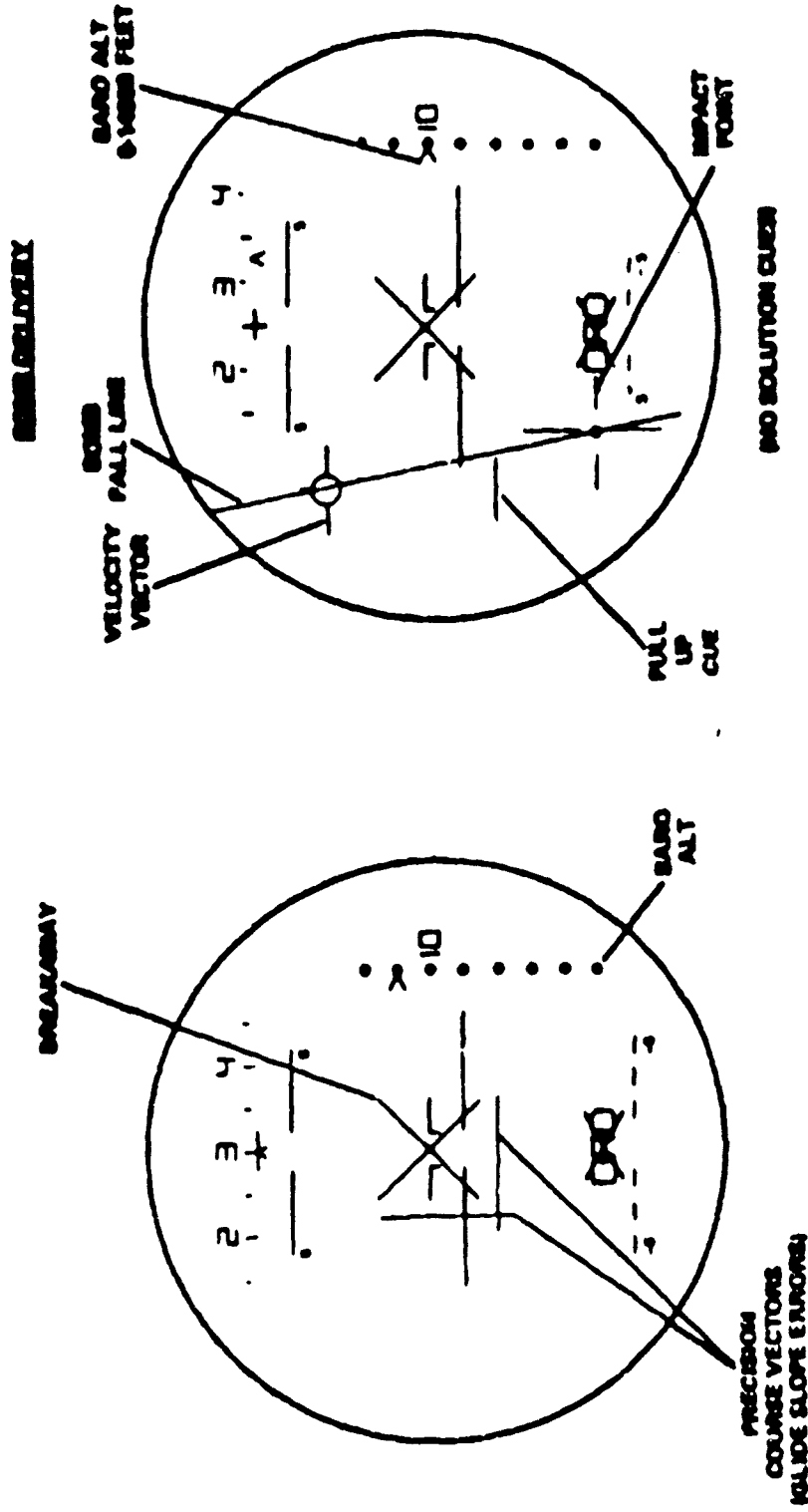


Figure 22. F-14A Display Modes

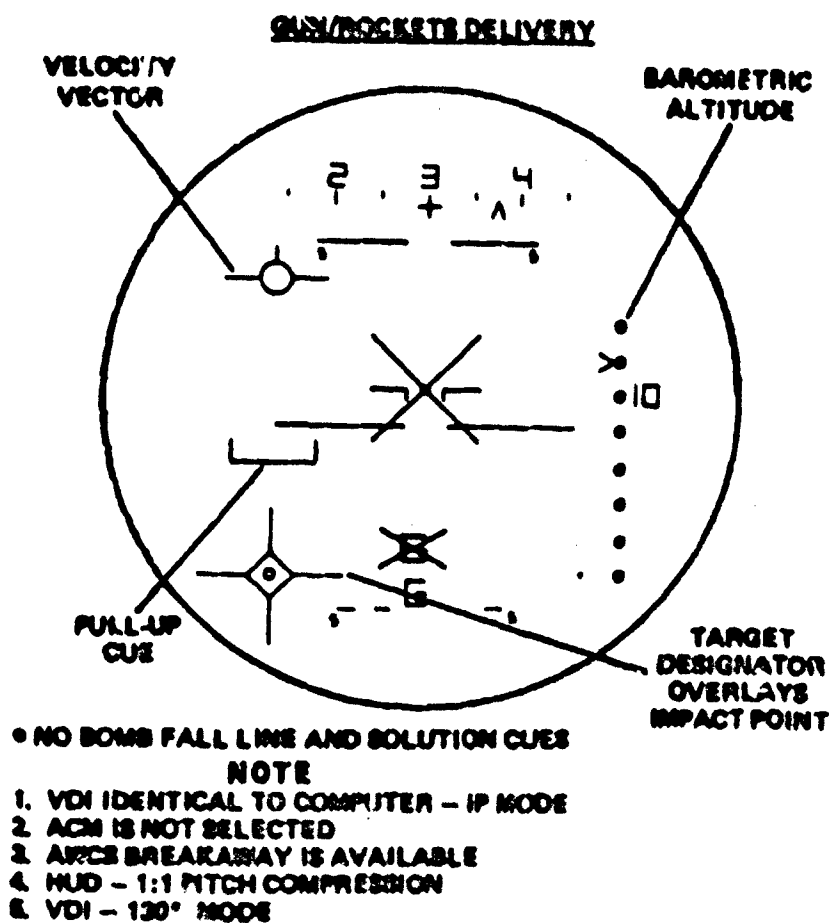


Figure 23. F-14A Display Modes

LANDING MODE/VECTOR SUBMODE

A/G MANUAL MODE

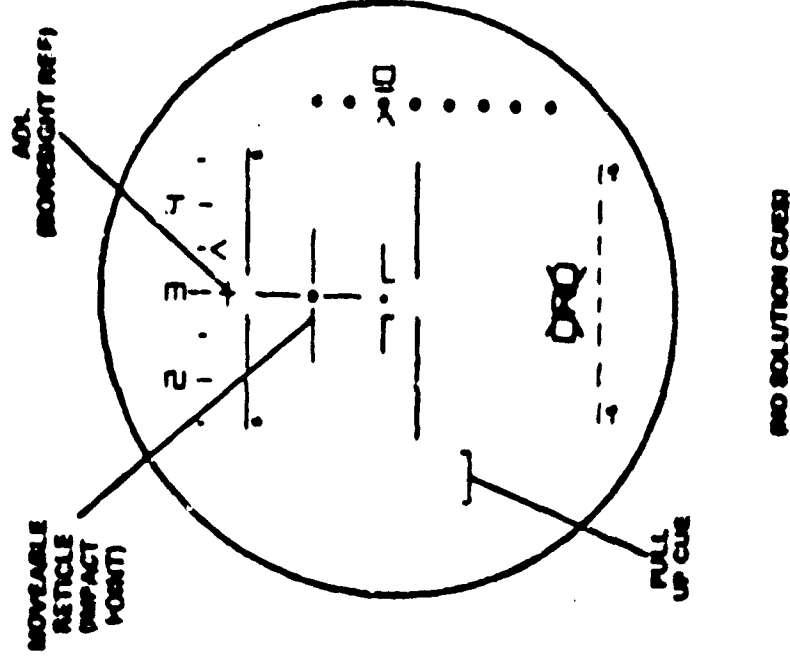
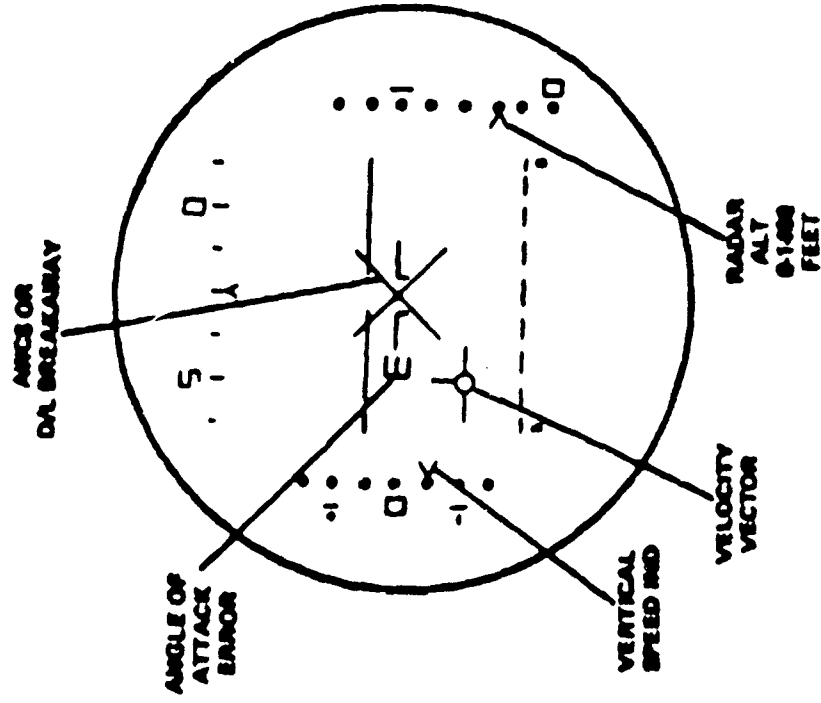


Figure 24. F-14A Display Modes

LANDING MODE/INIT SUBMODE

LANDING MODE/TACAN SUBMODE

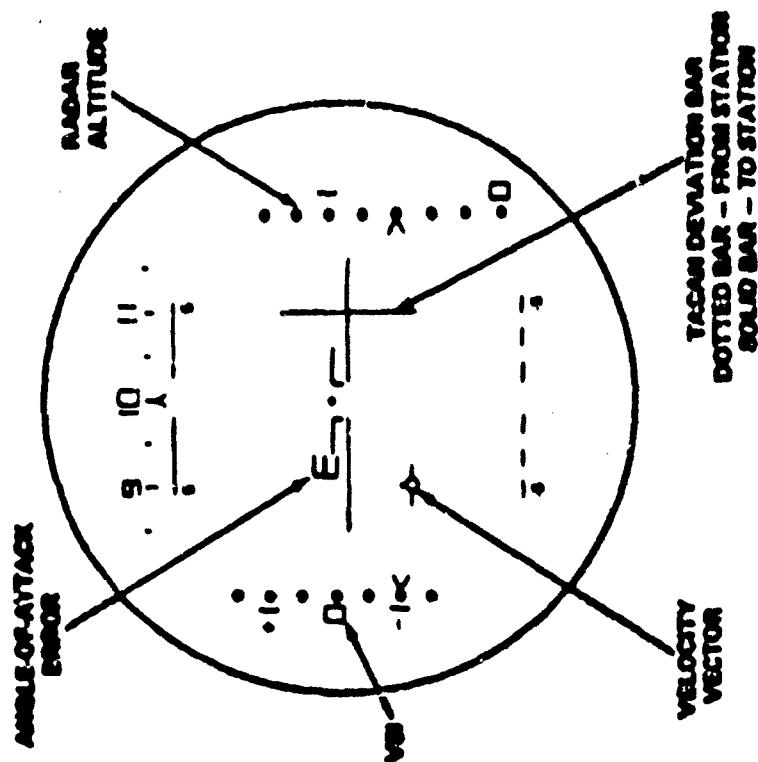
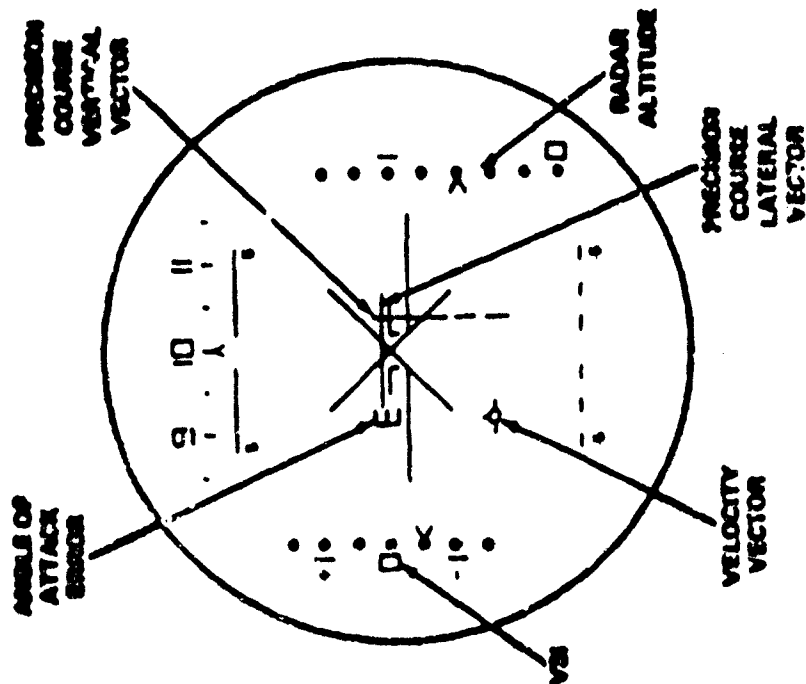


Figure 25. F-14A Display Modes

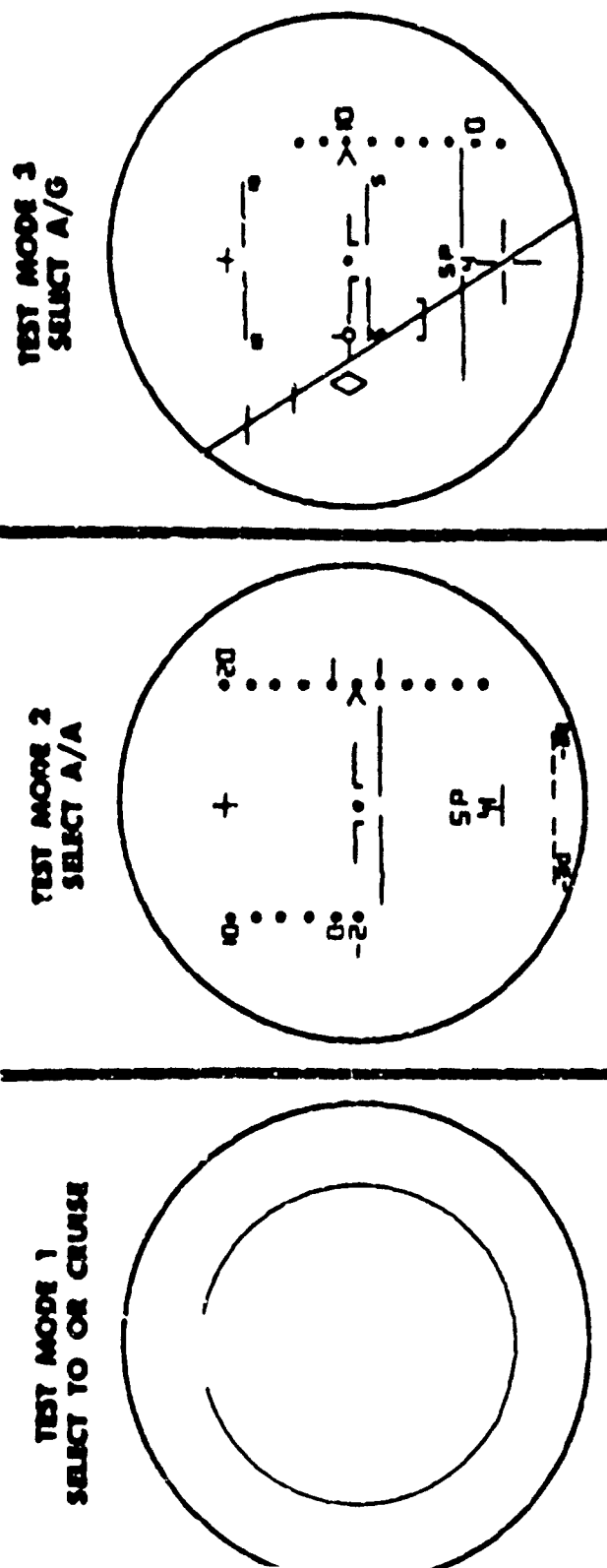


Figure 26. F-14A Test Modes

TEST MODE 4
SELECT LOG.

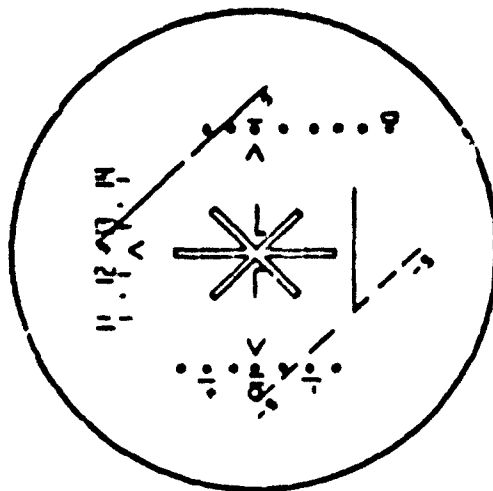


Figure 27. F-14A Test Modes

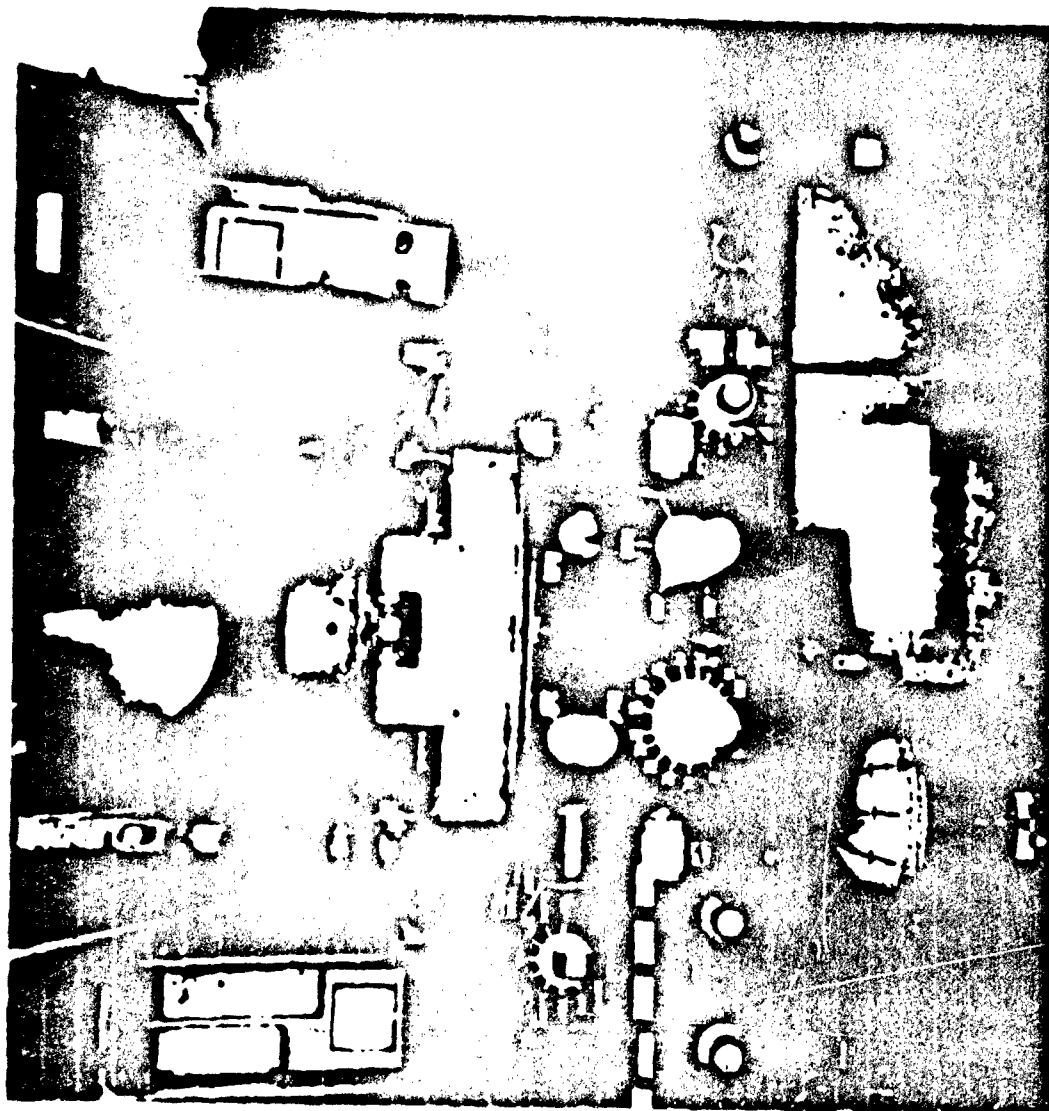


Figure 24. HUD Control Unit in the A-44 as viewed from the pilot's seat.

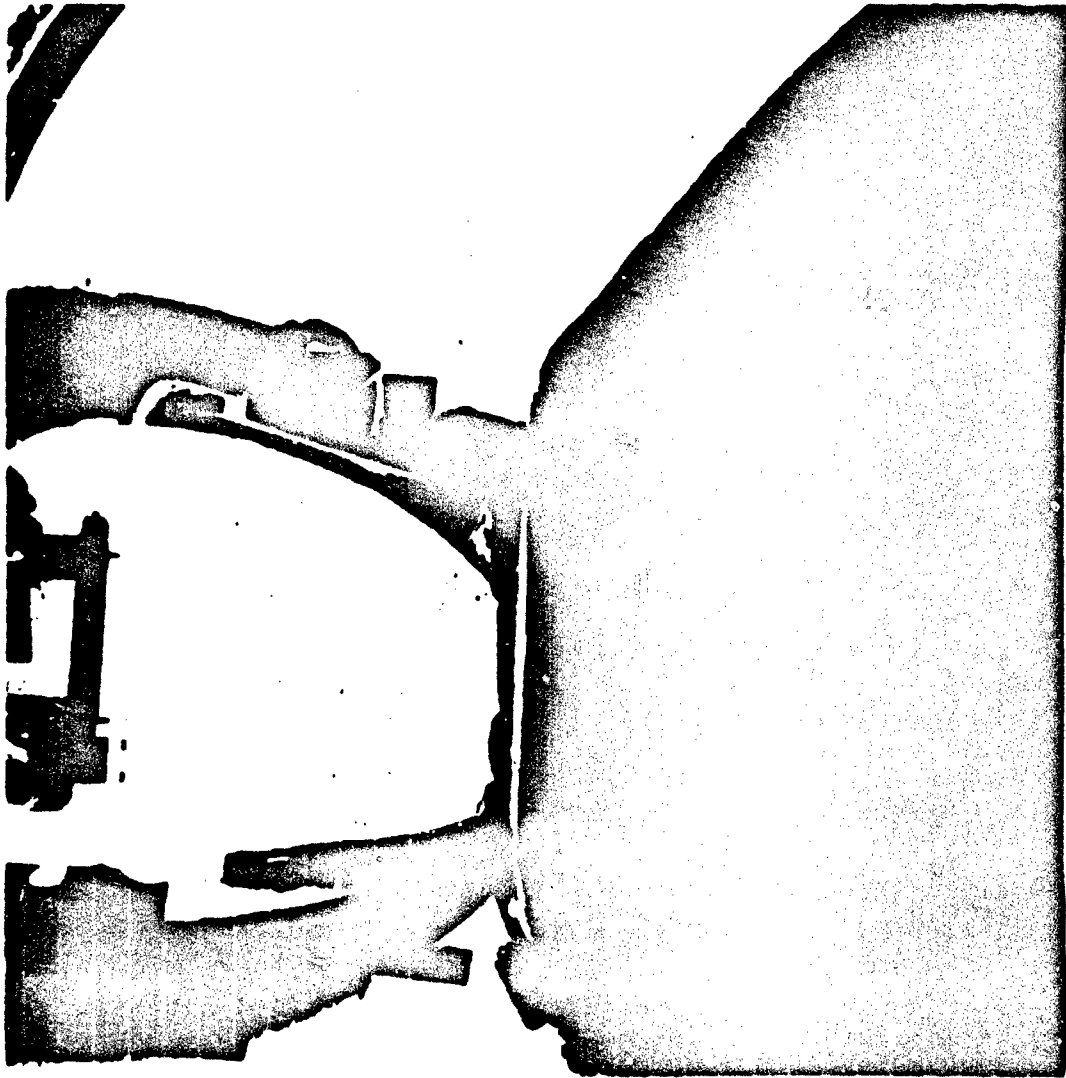


Figure 29. HUD Control Unit in the A-7E as viewed from the pilot's seat.

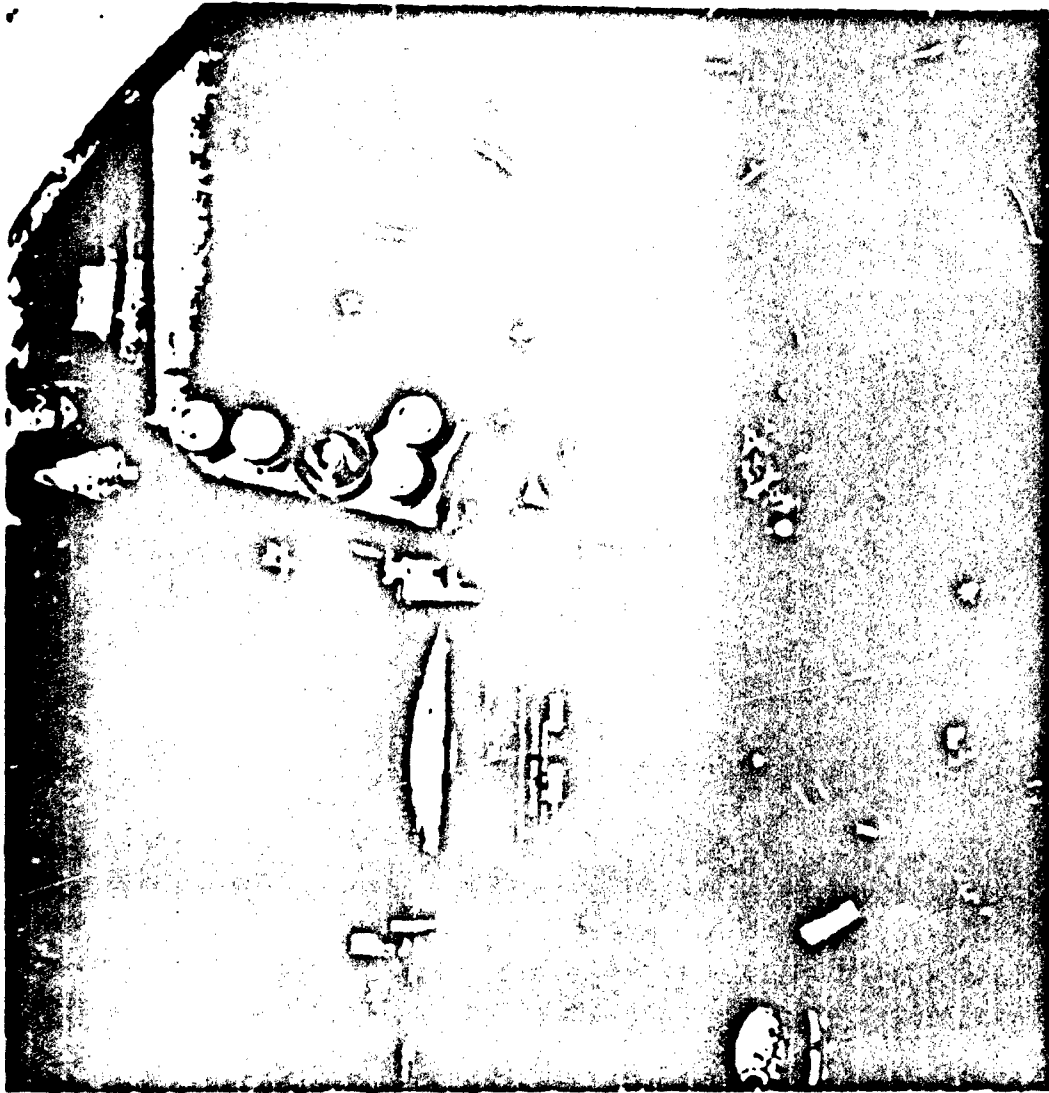


Figure 30. HUD Unit in the AV-8A as viewed from the pilot's seat.

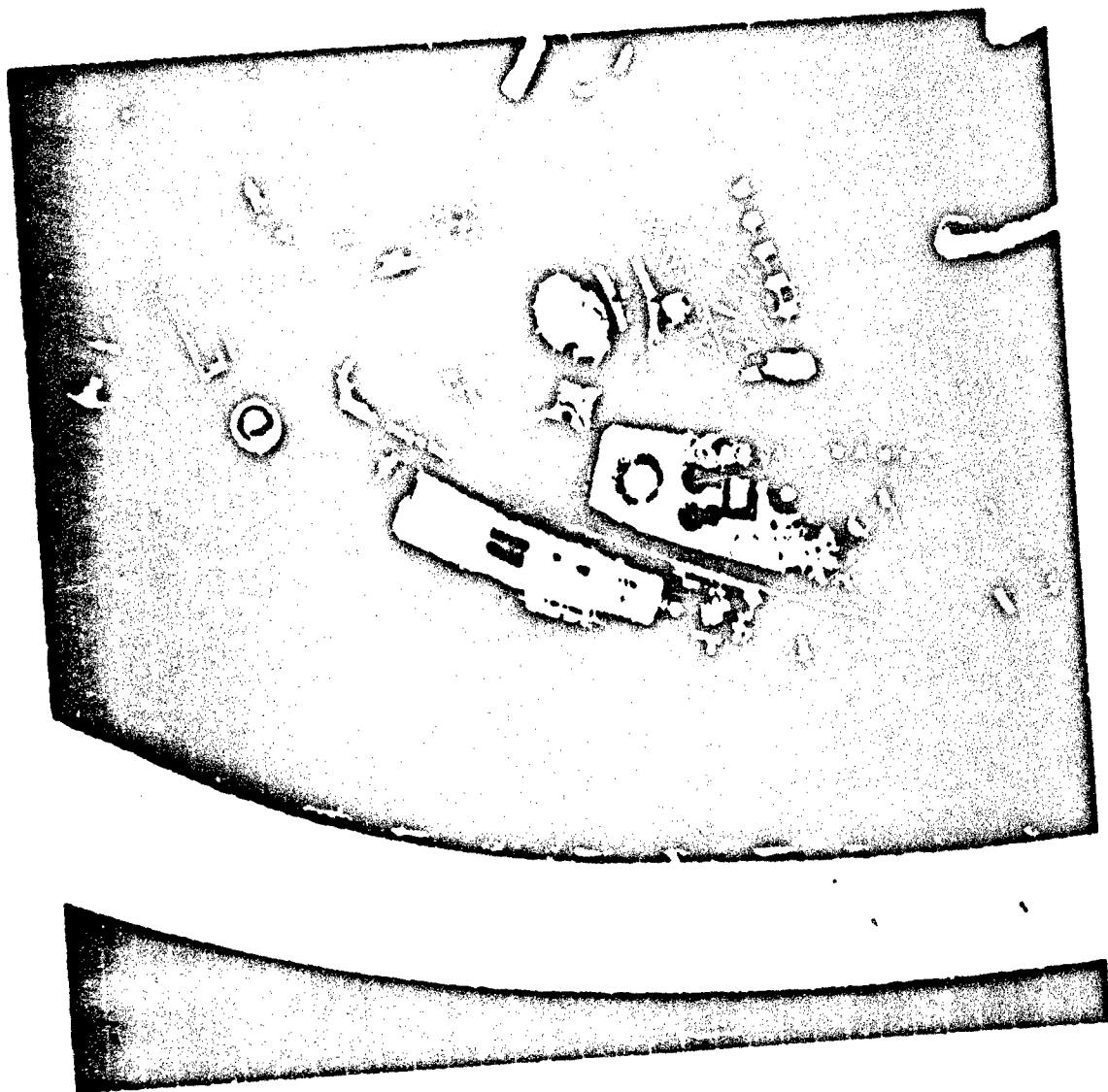


Figure 31. HUD Control Unit in the AV-8A as viewed from the pilot's seat.

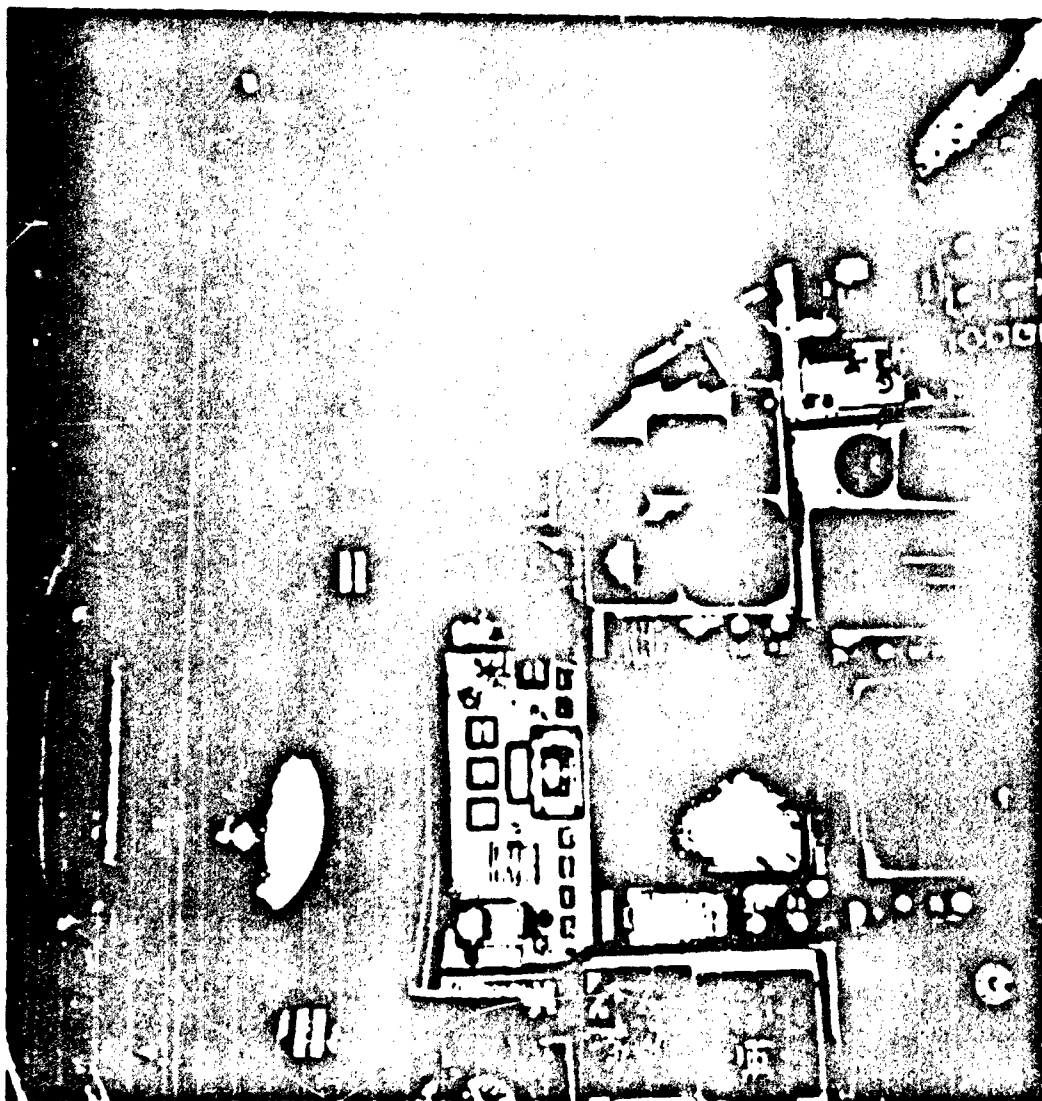


Figure 32. View of instrument panel and windscreen in the F-14A.

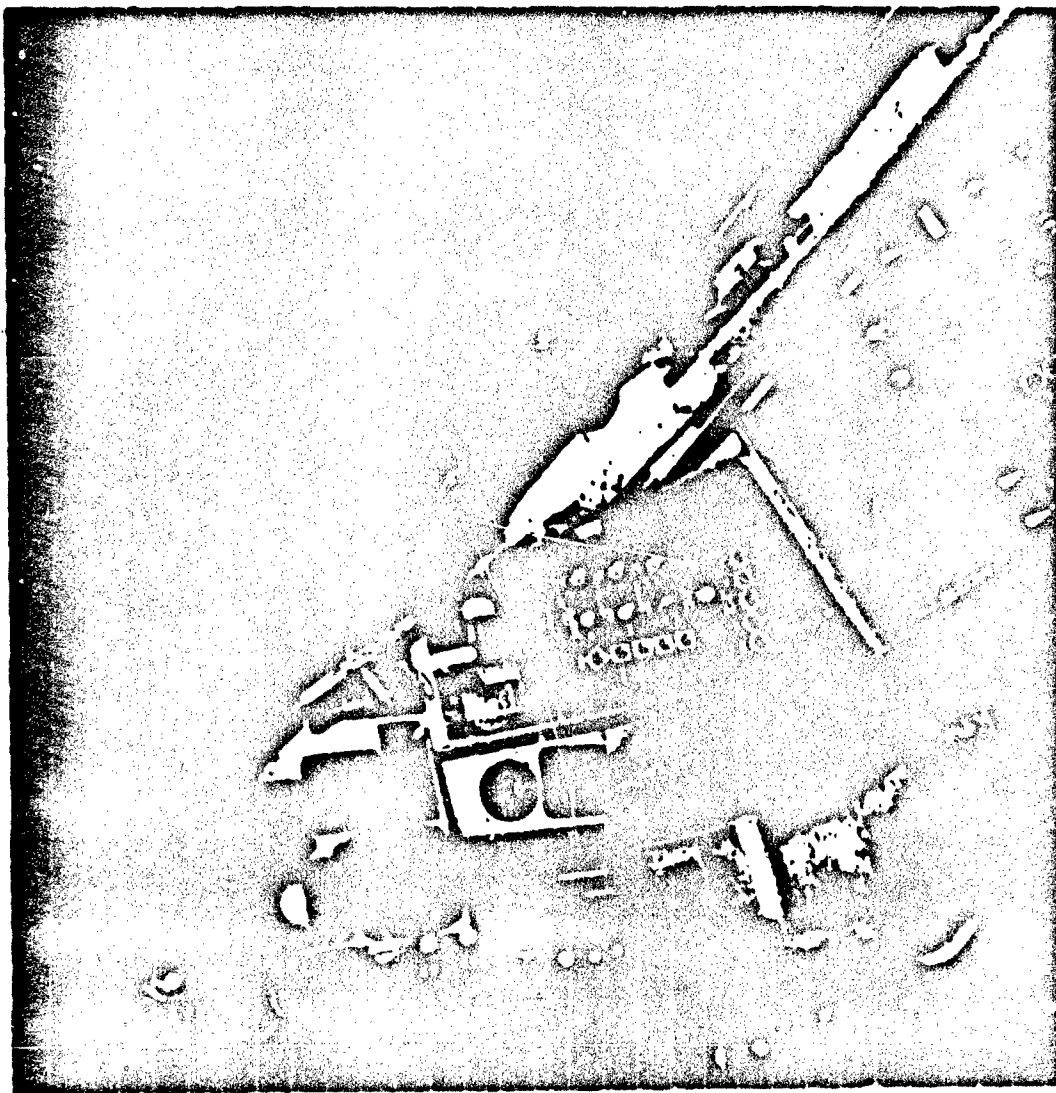


Figure 33. HUD Control Unit in the F-14A as viewed from the pilot's seat.

UNCLASSIFIED

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

20. (cont'd)

Operational HUDs were found to vary dramatically from each other and the military specification for HUDs, MIL-D-81641(AS), with respect to symbology and formatting. Furthermore, display clutter was reported by pilots to be a major problem. A comprehensive information processing evaluation of virtual image symbols and formatting under dynamic conditions was recommended.

Finally, none of the current Navy aircraft has a HUD control panel that complies to MIL-D-81641(AS), the military specification for HUDs. Pilots are required to bring their eyes back "into" the cockpit to ensure proper switch selection and, consequently, negate the primary purpose of maintaining a head-up mode.

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